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Geology of the North Caribou Lake Area, Northwestern Ontario

by

F.W. Breaks, I.A. Osmani and E.A. deKemp

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Abstract

This report presents a summary of geological, stratigraphic, structural and economic geology investigations of the North Caribou Lake metavolcanic–metasedimentary belt. The belt comprises 7 assemblages developed through 2 periods of volcanism and sedimentation between 2981±1.8 and 2932±3 Ma deposited upon a basement (2990±1 Ma), which consists, in part, of tonalite intrusive rocks. Salient features of the belt include less than 2978±3 Ma mature quartz arenite deposited on a stable shelf platform and abundance of overlying komatiitic metavolcanic rocks. A second period of epiclastic sedimentation at less than 2958.7±1 Ma produced a gradational sequence of alluvial fan conglomerate, feldspathic arenite and deep water, mudstone-dominant turbidites. The supracrustal rocks are enveloped by tonalite-granodiorite intrusive rocks and the latter produced deformation and local contact metamorphism at 2869±3 Ma. The structural history is marked by 3 ductile deformation events (D_1, D_2 and D_3) and 2 shearing episodes. Regional metamorphism of the Abukuma type occurred between 2981 and 2869 Ma and recorded a metamorphic field gradient of 400 to 590°C and less than 3 kilobars. Gold has been the major aim of recent exploration and occurs in 3 settings. The largest deposit, the East Bay (Opapimiskan Lake) contains five million tons grading 6.8 g/t gold hosted in grünerite-magnetite-chert iron formation.

Geology of the North Caribou Lake Area, Northwestern Ontario

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Ontario Geological Survey
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Introduction

The Opapimiskan Lake Project was a three-year multi-disciplinary survey involving 1:31 680 scale Precambrian and Quaternary mapping, mineral deposit, geophysical and surficial geochemical studies in the North Caribou Lake greenstone belt (NCLB). The integrated study commenced in 1984 with field work in the Eyapamikama Lake area (Breaks et al. 1984). In 1985, both Precambrian and Quaternary mapping continued to the southeast to Akow Lake (Breaks, Bartlett and deKemp 1985). The final period of Precambrian mapping and selected surficial geochemical work occurred in 1986 and involved a 1650 km^2 area covering the southeastern segment of the NCLB between Opapimiskan and Neawagank Lake (Breaks, Osmani and deKemp 1986). The Opapimiskan Lake Project was designed to encourage mineral exploration activity, the high potential of which was suggested by the recent discovery of important gold mineralization near Opapimiskan Lake (Hall and Rigg 1986). Increased interest in the area thus created a demand for a more recent geological and mineral deposit database. This final report provides a summary of the geological mapping segment of the joint project.

LOCATION AND ACCESS

The study area (Figure 1) is located between 10 and 160 km north of Pickle Lake. The centre of the area is at latitude 52°40′, longitude 90°30′. Easiest access to most of the area is by float- or ski-equipped aircraft from Pickle Lake. Regularly scheduled air service also exists between Pickle Lake and the nearby Weagamow Lake First Nations. An all-weather, gravel-surfaced road extending from Pickle Lake to Windigo Lake passes about 40 km south of Opapimiskan Lake, in the southern part of the belt. Both this road and the adit at the South Anticline property are linked by a winter road constructed in 1983.

FIELD PROCEDURES

Mapping (1:15 840) was mainly confined to the North Caribou Lake metavolcanic–metasedimentary belt. The bounding granitoid bodies were examined only in a narrow zone marginal to the belt. The geological field data were plotted on acetate sheets attached to 1:15 840 scale aerial photographs derived from enlargement of 1:63 360 scale aerial photographs obtained from the National Airphoto Library, Geological Survey of Canada, Ottawa. The data were then transferred to 1:15 840 scale base maps, which had been produced by enlargement of 1:50 000 scale National Topographic Series maps. The Universal Transverse Mercator (UTM) grid system has been used in reference to specific localities throughout this report. All localities mentioned in the report can be found on previously published maps (Breaks, Osmani and deKemp 1987a, 1987b; Breaks et al. 1986; Bartlett et al. 1985).

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Numerous personnel provided capable field assistance. Junior assistants comprised J. Carfrae, E. McLarty, S. Gibbins, M. Hitch, A. Cortis, C. Burk, P. Newman, K. Townsend, Z. Arias, K. Gillings, S. Scott, S. Jeffreys and R. Fogal. Independent mapping was carried out by A. Cortis, Z. Arias, K. Woytiuk, K. Manser, S. Foley and E. Jennings. D.L. Gibb and K. Booth served as excellent cooks for the field parties.

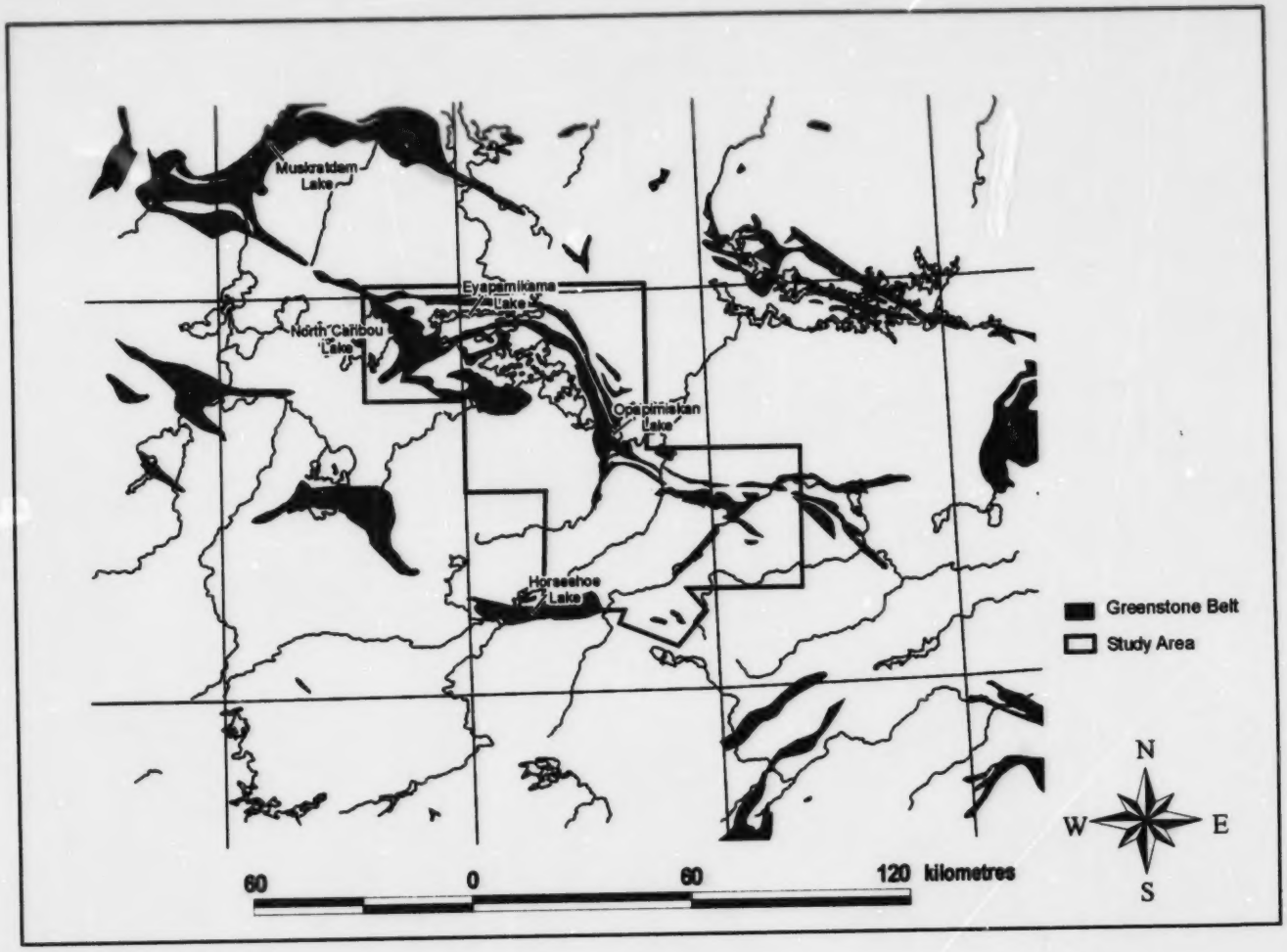


Figure 1. Map showing the location of the North Caribou Lake area.

The authors benefitted from discussion, in the field, with P. Finamore, H. Shields, H. Wallace and J. Wood (Ontario Geological Survey) and G. Gorzynsky (Northern Dynasty Exploration Limited). D. Rigg (Dome Mines Group) led an informative excursion underground at the Musselwhite property on Opapimiskan Lake. Fruitful pre- and post-field season discussions were had with R. Hall (Esso Minerals Canada) and J. Satterly, respectively. Gratitude is also owing to R. Hall for providing a copy of exploration results from the Forester Lake claim-group of Esso Minerals, Canada. Office assistance was provided by I. Osmani and R. Fogal subsequent to the field season. The authors thank personnel of Moss Resources Limited/Van Horne Gold Exploration Limited, especially J. Hodge, and J. Adams, for permission to visit the Van Horne property at Opapimiskan Lake and for the generous provision of valuable maps and data concerning their numerous properties in the North Caribou Lake belt. Special thanks are extended to Ministry of Natural Resources personnel, at both Sioux Lookout and Pickle Lake, for providing logistical support to the field party. Iva Sherritt is thanked for typing of the manuscript.

PREVIOUS GEOLOGICAL WORK

The North Caribou Lake metavolcanic–metasedimentary belt was first mapped by Satterly (1941) and later covered by reconnaissance geological surveys (Emslie 1962; Thurston, Sage and Siragusa 1979). The Forester Lake area, in the southeastern portion of the belt, has been examined by the latter 2 geological surveys and by Sage and Breaks (1982). Andrews, Sharpe and Janes (1981) undertook limited mapping and described the Musselwhite gold occurrence near Opapimiskan Lake. The belt was also re-examined at a reconnaissance scale by R. Hall to complement detailed mapping of the Opapimiskan Lake area, as part of PhD research at Queen's University. The area was covered by an airborne magnetometer survey on scale of 1 inch to 1 mile in 1960 (Ontario Department of Mines–Geological Survey of Canada 1960).

General Geology

The North Caribou Lake supracrustal greenstone belt forms part of the Sachigo Subprovince (Figure 2), which is marked by small, arcuate and irregularly shaped metavolcanic–metasedimentary belts surrounded mainly by younger granitic rocks. Lithologic and geochronological similarities in the stratigraphic succession of several of these isolated belts (e.g., North Caribou Lake, Windigo Lake, North Spirit Lake and Wunnummin Lake belts) imply a common evolutionary development. These belts conceivably may represent remnants of a single, once continuous "megabelt". Some of these features are distinct from developmental stages recognized in supracrustal belts to the south in the Uchi and Wabigoon subprovinces (Stott and Corfu 1991; Blackburn et al. 1991).

The North Caribou Lake belt (NCLB) can be subdivided into 8 lithotectonic supracrustal assemblages: Agutua Arm metavolcanic assemblage (AAV), Keeyask Lake metasedimentary assemblage (KLS), Keeyask Lake metavolcanic assemblage (KLV), South Rim metavolcanic assemblage (SRV), North Rim metavolcanic assemblage (NRV), Opapimiskan Lake metavolcanic assemblage (OLV), Forester Lake metavolcanic assemblage (FLV), and Eyapamikama Lake metasedimentary assemblage (ELS). These abbreviations will be maintained throughout the text. Another unit mentioned extensively in the text is the Lundmark Lake metavolcanic unit (LLV).

Since this report was originally written, the terminology for the area has been changed (Table 1; *see also* Thurston, Osmani and Stone 1990, Figure 5.3 and Table 5.1).

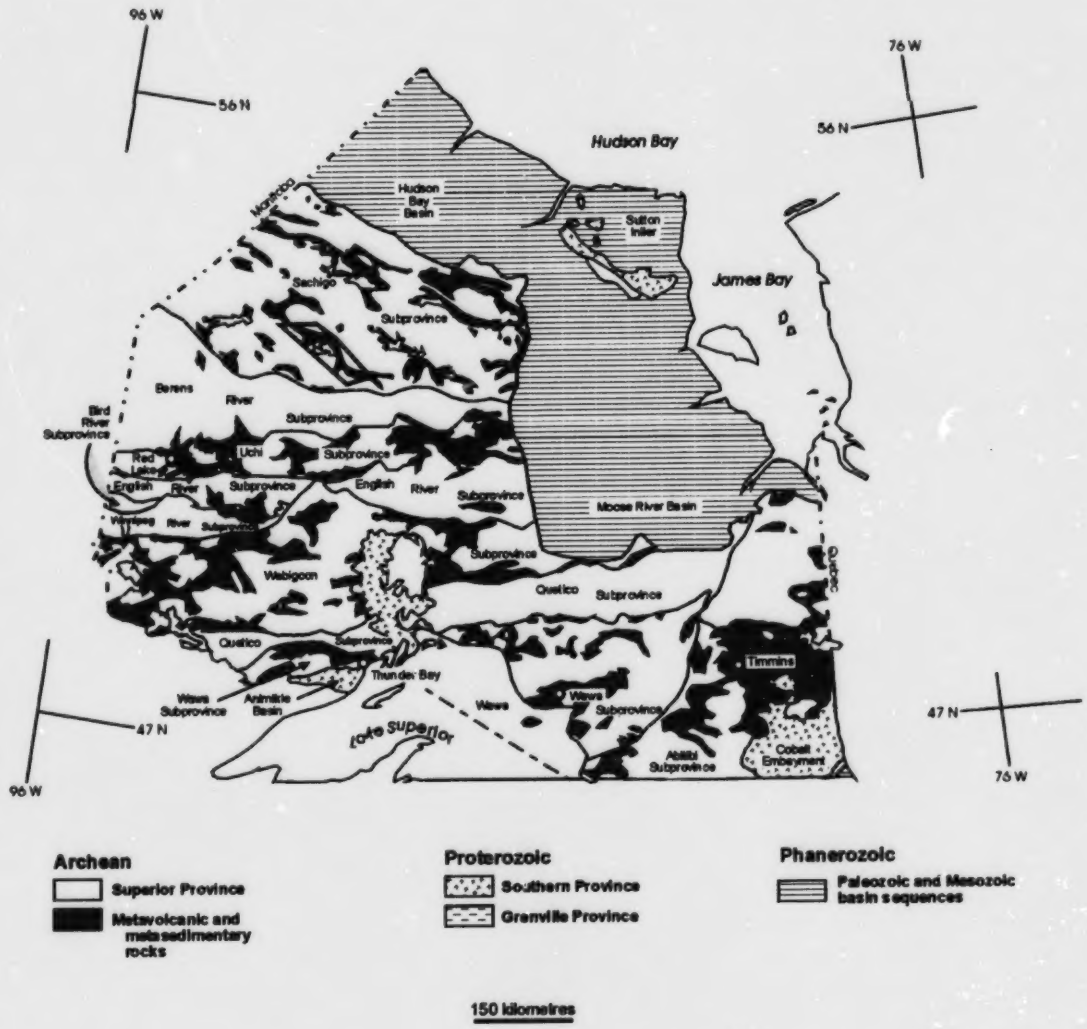


Figure 2. Geological location of the North Caribou Lake greenstone belt within the Superior Province of northwestern Ontario.

U/Pb age determinations have been undertaken on the AAV, KLS and ELS by deKemp (1987) and on the NRV and SRV by Dr. D. Davis, Jack Satterly Geochronological Laboratory, Royal Ontario Museum, Toronto. All ages are from deKemp (1987) unless otherwise referenced.

Several supracrustal assemblages (KLV, LLV, OLV and FLV) contain a high percentage of komatiitic metavolcanic rocks. These rocks, which occur throughout the NCLB, are composed of massive, pillowed and variolitic flows and rare hyaloclastic breccias. Associated felsic and intermediate metavolcanic rocks are rare to absent. Most of the major magnetite-grünerite-chert banded iron formation units and significant gold mineralization are hosted within these komatiite-rich metavolcanic assemblages.

The oldest supracrustal rocks comprise the AAV felsic to mafic tholeiitic metavolcanic sequence (2981±2 Ma) situated at the west end of the NCLB. Together with an unconformably overlying thin unit of mature quartz arenite and minor stromatolitic units comprising the KLS, this area is interpreted as a stable shelf, platformal volcano-sedimentary edifice. The basement to the platformal sequence is not known, but is possibly sialic, as the tonalitic Weagamow batholith (2990±2 Ma) slightly predates felsic metavolcanic rocks of the AAV.

Extrusion of stratigraphically overlying komatiitic metavolcanic rocks of the KLV and possibly correlative OLV, FLV, and LLV further to the southeast marks a major change in greenstone belt development from platformal, stable shelf environment to a rift-fill phase. Clastic metasedimentary rocks of the ELS, the youngest supracrustal assemblage, dominate the NCLB and comprise about 50% of the belt. The proportion of clastic metasedimentary rocks is distinctly higher than in most greenstone belts of the Uchi and Wabigoon subprovinces. Stratigraphically, this thick clastic sequence lies above flanking subaqueous, tholeiitic mafic metavolcanic-rich assemblages of the NRV and SRV. Important ELS rock types include alluvial fan conglomerate, arenite, wacke and mudstone.

Table 1. Abbreviations used in this report, and revisions in terminology, which pertain to the North Caribou Lake area, subsequent to the completion of this report.

This Report		Revised Terminology (Thurston, Osmani and Stone 1991)
Terminology	**Abbreviation**	
North Caribou Lake greenstone belt	NCLB	North Caribou greenstone belt
Agutua Arm metavolcanic assemblage	AAV	Agutua Arm assemblage
Keeyask Lake metasedimentary assemblage	KLS	Keeyask assemblage
Keeyask Lake metavolcanic assemblage	KLV	
South Rim metavolcanic assemblage	SRV	South Rim unit (of McGruer assemblage)
North Rim metavolcanic assemblage	NRV	North Rim unit (of McGruer assemblage)
Opapimiskan Lake metavolcanic assemblage	OLV	Opapimiskan unit (of McGruer assemblage)
Forester Lake metavolcanic assemblage	FLV	Forester unit (of McGruer assemblage)
Eyapamikama Lake metasedimentary assemblage	ELS	Eyapamikama assemblage (north of Opapimiskan Lake) Zeemal–Heaton assemblage (south of Opapimiskan Lake)
Lundmark Lake metavolcanic unit	LLV	Lundmark Lark metavolcanic formation (of Keeyask assemblage)
Schade Lake gneissic complex		Schade gneissic complex
North Caribou Lake batholith		North Caribou batholith

The NCLB is bounded on all sides by metamorphosed massive, foliated and gneissic felsic plutonic rock. Two intrusive complexes, the North Caribou Lake batholith and the Schade Lake gneissic complex, composed of tonalite, granodiorite, quartz diorite and diorite, have U/Pb ages of 2870±2 Ma and 2856±2 Ma, respectively.

Metamorphosed mafic and ultramafic dikes and masses are mainly restricted to the FLV and OLV. Most notable is the Karl Lake layered complex, which is composed of peridotite, pyroxenite, gabbro and anorthositic gabbro.

Unmetamorphosed intrusive rocks are rare in the study area. Several north- to northwest-striking diabase dikes may belong to the Pickle Crow diabase swarm and, hence, could be Proterozoic.

Regional metamorphism is predominantly of the Abukuma type, and varies between low and medium grade. Very local departures, marked by an increase in load pressure, are reflected in the appearance of kyanite. Distribution of regional metamorphic assemblages within the NCLB is varied, being mainly low grade in the northwest and rising to medium grade toward the southeast. Regional metamorphism, which reached 550°C and 3 kilobars load pressure, is deduced to have developed at an age earlier than in adjacent subprovinces. The minimum age for the metamorphism is constrained by the diapiric emplacement, at 2870 Ma, of the North Caribou Lake batholith, which both warped pre-existing regional isograds and overprinted these by an amphibolitic contact aureole.

Primary stratigraphic relationships have been variably obscured by 3 periods of folding and at least 2 brittle–ductile faulting episodes. Structural elements relating to the earliest deformation, D_1, are only locally discernible as tight to isoclinal mesoscopic F_1 folds in banded iron formation. Similarly, associated S_1 foliations, which can be penetratively developed, are only sporadically recognizable, and are most commonly preserved as inclusion trains in porphyroblastic minerals. D_2, the most pervasively developed deformation event in the NCLB, imposed a penetrative planar fabric (S_2), stretching lineations, closed to open asymmetric mesoscopic and macroscopic F_2 folds, and boudinage upon the supracrustal assemblages. Macroscopic F_2 folds are best recognized in banded iron formation units, such as at Opapimiskan and Sage lakes. Well-developed F_2 axial planar cleavage is commonly a preferred locus for syn-D_2 shearing and auriferous quartz vein emplacement. On a macroscopic scale, numerous left-lateral syn-D_2 shear zones are developed in the NCLB, and are apparently controlled by lithologic contacts. D_3, the final ductile phase of deformation, is sporadically distributed. This event is locally apparent as mesoscopic, open to gentle, asymmetric F_3 warps, chevron crenulations, and minor S_3 crenulation cleavage overprinting D_2 fabric elements.

Local superposition of F_1–F_2 and F_1–F_2–F_3 fabric elements has produced spectacular fold interference structures. Types 1 and 3 classes of such folds (Ramsay 1967) are particularly conspicuous in the Opapimiskan Lake area.

The final episode of deformation is reflected in brittle, north-top northwest-striking transverse faulting, which has controlled emplacement of posttectonic olivine lamprophyre dikes (Hall and Rigg 1986, p.129).

The study area is extensively covered by Pleistocene glacial deposits relating to the last Wisconsin ice advance and retreat (Prest 1963). Lodgement till represents the most extensive advance deposit and is highly conspicuous as south- to southwest-trending drumlins. During glacial ice retreat, a variety of ablation deposits were formed. These include glaciolacustrine varved sediments of Lake Agassiz glaciofluvial deposits (eskers, kames and outwash sand-gravel). Abandoned shoreline features are local, apparent as beach ridges, wave-cut notches and boulder lag concentrates.

LITHOTECTONIC SUPRACRUSTAL ASSEMBLAGES OF THE NORTH CARIBOU LAKE BELT

The following text will now focus upon the geologic and petrographic features of the important supracrustal assemblages of the North Caribou Lake belt.

Agutua Arm Metavolcanic Assemblage

DISTRIBUTION, STRATIGRAPHIC AND TEMPORAL RELATIONS

This 70 km^2 metavolcanic-rich assemblage occupies most of the western extremity of the NCLB (Figure 3, back pocket) and lies in intrusive contact with tonalite-granodiorite batholiths (Weagamow and Round Lake batholiths). Temporal relations with the SRV and NRV are unknown as these assemblages either occur in fault contact (SRV) or exhibit apparent spatial separation (NRV). Eastern limits are defined by an angular unconformity with the overlying north-northwest-striking KLS. The extreme northwestern extent of the AAV is uncertain due to very poor exposure here. Aeromagnetic data (Ontario Geological Survey 1985) suggest a continuation of these rocks from Agutua Arm to the settlement of Round Lake. The U/Pb zircon age of 2981±2 Ma (deKemp 1987) corroborated the earlier stratigraphic interpretation of Breaks et al. (1984) that the AAV represented the oldest metavolcanic rocks in the NCLB. These rocks plausibly acted as a substrate for succeeding supracrustal accumulations in the belt.

A gross southwest-striking stratigraphy is suggested by 2 felsic to intermediate pyroclastic and/or volcaniclastic units that occur near the northeast end of Agutua Arm. These units dip shallowly to the southeast. Stratigraphic tops were obtained from only 1 locality, at the northeast end of Agutua Arm. Quartz amygdules are concentrated at the inferred top of an altered mafic flow, indicating upright, southeast-facing stratigraphy.

ROCK TYPES

Mafic Metavolcanic Rocks

Massive, fine-grained, equigranular mafic flows of normal to magnesium-tholeiitic composition predominate in the AAV (Figure 4). These rocks are mainly green-black to yellow-green on weathered surfaces. Massive flows are best preserved on Pakiagama Lake and on the North Caribou River.

Subophitic primary textures, plagioclase and hornblende phenocrysts and quartz-rich amygdules are best preserved in the central parts of the chlorite zone. There, the fine-grained massive flows consist of 50 to 60% randomly oriented, moderately to strongly epidotized plagioclase laths partially embedded in granoblastic aggregates of hornblende. Accessory quartz is present in some rocks.

Plagioclase phenocrysts in mafic flows vary from 54 to 20 mm in length, and, in shape, from euhedral laths to globules. The strongly altered phenocrysts can form as much as 60 to 70% of the rock. Rarely, mafic flows display a size gradation of plagioclase phenocrysts. Hornblende porphyroblasts, possibly after pyroxene, occur locally in mafic flows and are generally small, with diameters averaging 2 mm. Quartz amygdules occupy up to 10% of some mafic flows in the north and northeast parts of Agutua Arm.

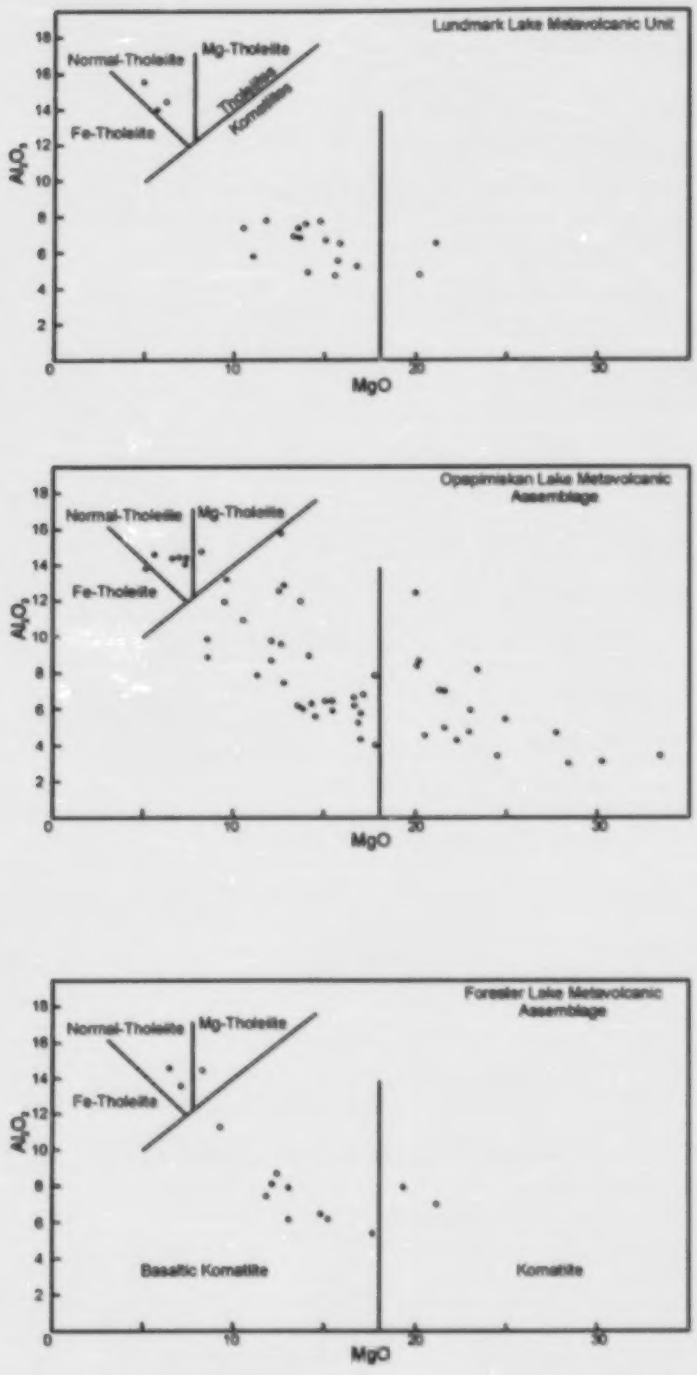
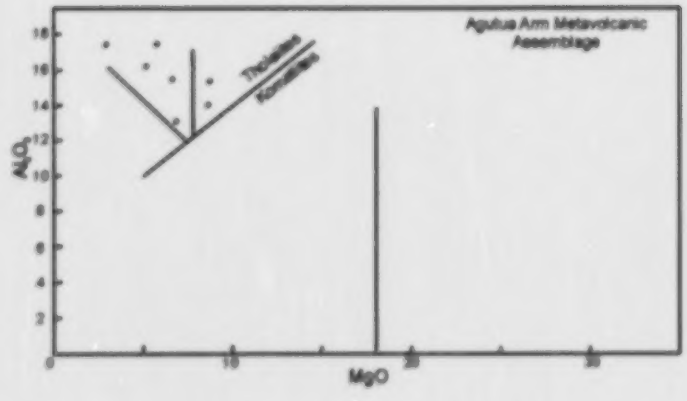
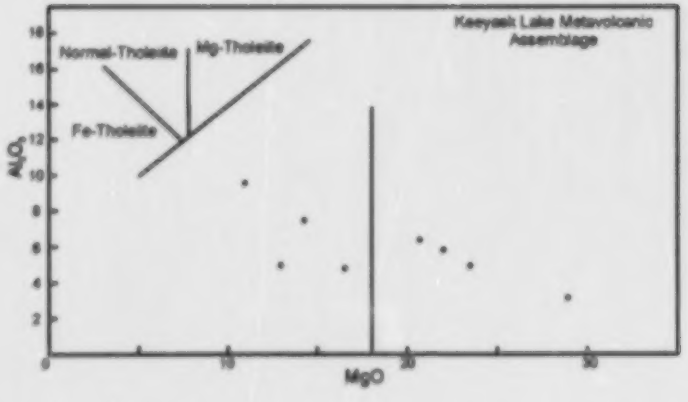
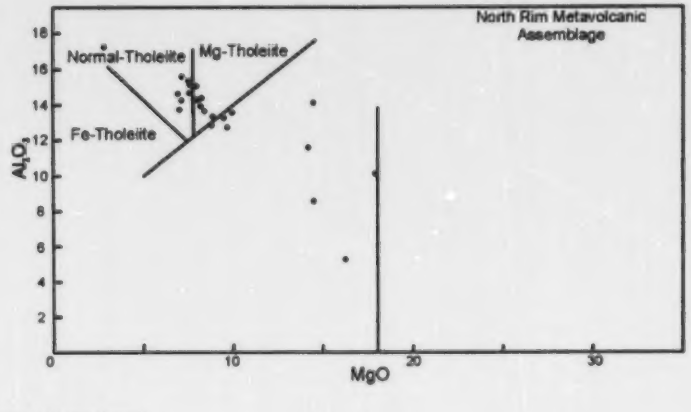


Figure 4. MgO versus Al_2O_3 (weight %) diagram for metavolcanic rocks from the North Caribou Lake belt.







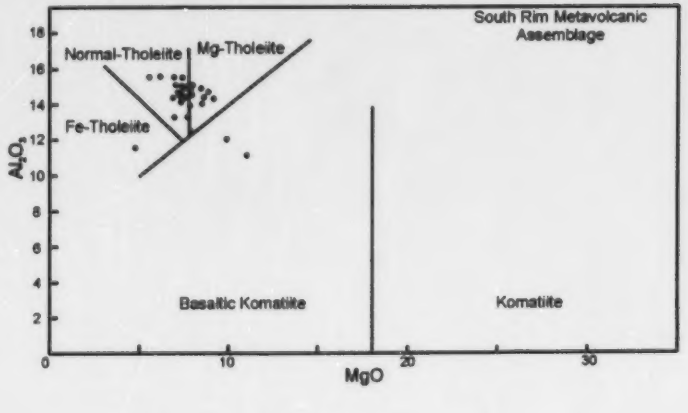


Figure 4. continued.

Pillow structures are rare in the AAV. These were found at 2 localities at the western edge of the map area at the entrance of Agutua Arm and unconformably underneath chert pebble conglomerate of the KLS near Centre Lake (local name). Piroshco and Shields (1985, p.281) interpreted a paleosol weathering zone in these pillowed mafic metavolcanic rocks (Photo 1) based upon a 10 m thick zone of extensive sericitization, irregular oxidation and intense fractures that gradationally increases toward the unconformity surface. Fragmental mafic metavolcanic rocks are also rare in the AAS. Mafic breccia of possible hyaloclastite origin is well preserved only at 1 locality.

Felsic and Intermediate Metavolcanic Rocks

The most extensive felsic and intermediate metavolcanic unit in the NCLB occurs in the AAV. This mass lies north of the North Caribou River between the northeast shore of Agutua Arm and 0.5 km west of the southwesternmost bay of Eyapamikama Lake. Its extent was previously mostly undocumented except for shoreline exposures mapped by Satterly (1941) and Thurston, Sage and Siragusa (1979).

Photo 1. Quartz arenite of the Keeyask Lake metasedimentary assemblage unconformably overlying pillowed mafic metavolcanic rocks (Agutua Arm metavolcanic assemblage). The hematite-sericite-bearing unit on the right possibly represents a regolith. Hammer is 0.4 m in length.

The intermediate and felsic sequence has poorly defined northern and southern boundaries owing to a paucity of outcrop. The eastern contact with the KLS is exposed locally (Photo 1) and represents an important angular unconformity.

Bedding thickness of pyroclastic rocks is on the order of one to several metres, and, in some places, up to 10 m or more. Internal stratification is generally lacking or crudely developed.

Well-preserved, generally unbedded, intermediate and felsic metavolcanic rocks are well exposed between the northeastern end of Pakiagama Lake and the base of the KLS and include felsic tuff, lapilli tuff, lapillistone and possible flows. Most are fragment-supported with fragments composing at least 80% of the rock. Lithic fragments are most common, ranging in size from 1 to 7 cm in diameter. These are typically aphanitic, plagioclase rich and, in some cases, plagioclase phyric.

Crystal fragments in lapilli tuffs are mainly plagioclase in the 2 to 5 mm range. These generally compose 5% or less of the rock. Plagioclase-rich fragments, both lithic and crystal, are typically highly sericitized, as is the plagioclase-rich part of the matrix. Quartz commonly accompanies plagioclase in the very fine-grained matrix.

Fragment:matrix ratios are highly varied, but, in general, the matrix dominates. Fragments are mainly lithic (wholly volcanic) and crystal, with plagioclase phenocrysts more common than quartz phenocrysts. Vitric (pumiceous) fragments occur only locally. Lithic fragments include intermediate (commonly plagioclase phyric) and felsic varieties, supported by slightly more mafic matrix. Pre-strain lithic fragment sizes are in the fine to coarse lapillus range. It is common for rocks to contain 2 or 3 types of lithic fragments. Some rocks contain both intermediate and felsic fragments.

The western part of the unit is best exposed on the shores and islands of Agutua Arm, where the rocks are generally coarsely fragmental. Moderate to strong deformation of most rocks has resulted in conversion of original fragment shapes to oblate or, more rarely, prolate ellipsoids. This has rendered determination of original shape and, therefore, method of fragmentation impossible, and the rocks have thus been termed volcaniclastites. These rocks commonly do not exhibit obvious layering on a megascopic scale. This may be, in part, a function of the small size of outcrops (5 to 10 m across).

Keeyask Lake Metasedimentary Assemblage

The Keeyask Lake metasedimentary assemblage (KLS) predominantly consists of quartz arenite, mudstone and banded iron formation. Minor rock types include quartz wacke, plagioclase arkosic arenite and chert. The assemblage is about 20 m thick and strikes for 3.5 km between Centre Lake and near Pakiagama Lake (Figure 5). Typical rocks composing the KLS can most readily be observed at an outcrop situated midway along the Eyapamikama–Pakiagama lakes portage.

The exposed beds consistently face to the east based upon observations of cross-bedding in quartz arenite, grain gradation in the upper siltstone unit and by stromatolite morphology. Dips of the beds range from 80°E to vertical.

ROCK TYPES

Texturally and mineralogically mature quartz arenite dominates the KLS (Photo 2). These beige to grey-white rocks compose the lower part of the KLS and attain a thickness up to 10 m (Figure 6). A 5 to 30 cm

thick basal chert pebble conglomerate occurs sporadically and immediately lies above a mafic metavolcanic regolith zone (Piroshco and Shields 1985). Quartz wacke occurs in association with quartz arenites throughout the section. Stromatolitic mudstone is a minor unit, less than 15 cm thick, that conformably overlies the quartz arenite. Thinly to very thinly bedded mudstones up to 5 m thick overlies this unit. The top of the KLS section may either be capped by thinly bedded banded iron formation, chert, or dolomitic calcarenite (Photo 3).

Quartz Arenite

Bed forms within the quartz arenites are dominantly planar and trough cross-beds, ripple cross-beds and planar-stratified beds. These bedform geometries are defined by detrital heavy minerals and authigenic tourmaline along original depositional laminae. Bedform geometry throughout the Keeyask Lake metasedimentary section indicates current directions are random to bimodal. Possible herringbone cross-beds have been observed in several localities directly above reactivation surfaces cut into ripple crests.

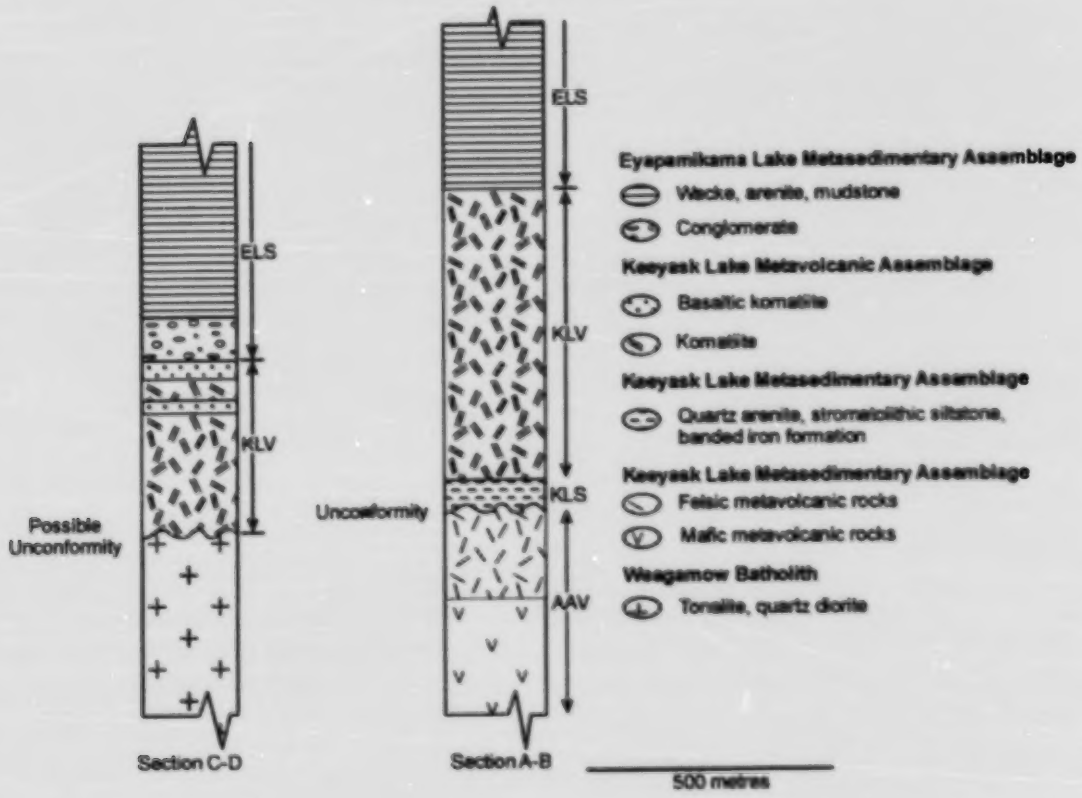


Figure 5. Stratigraphic relations of units in the western Eyapamikama Lake area.

Quartz pebble lags are common at the base of foresets and some imbricated clasts occur within 1 to 5 cm thick interbeds. Maximum foreset angles are about 250 to 300°. Also present are massive 10 to 15 cm coarse-grained quartz arenite interbeds, which contain angular sericite-hematite rip-up clasts. These beds sharply truncate underlying bedforms and tend to be laterally discontinuous.

Massive, planar cross-bedded and ripple cross-bedded units occur throughout the quartz arenite section. At some locations, a zonation is evident from massive to trough cross-bedded and then to rippled beds from the base of the section to the top (Arias 1986). Interstratified with cross-bedded zones are thin

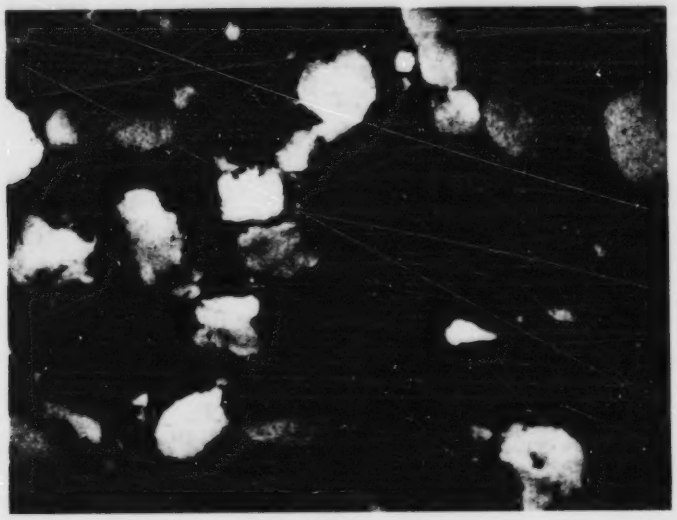


Photo 2. Photomicrograph of a texturally and mineralogically mature quartz arenite, typical of the Keeyask Lake metasedimentary assemblage from exposure detailed in Figure 6. Note well-rounded, bimodal habit of the quartz grains.

Photo 3. Angular, intraformational breccia in dolomitic calcarenite unit situated 1 m stratigraphically below fuchsite-carbonate-altered komatiite of the Keeyask Lake metavolcanic assemblage. Exposure located about 10 m from quartz arenite unit of Figure 6. Coin diameter is 2.3 cm.

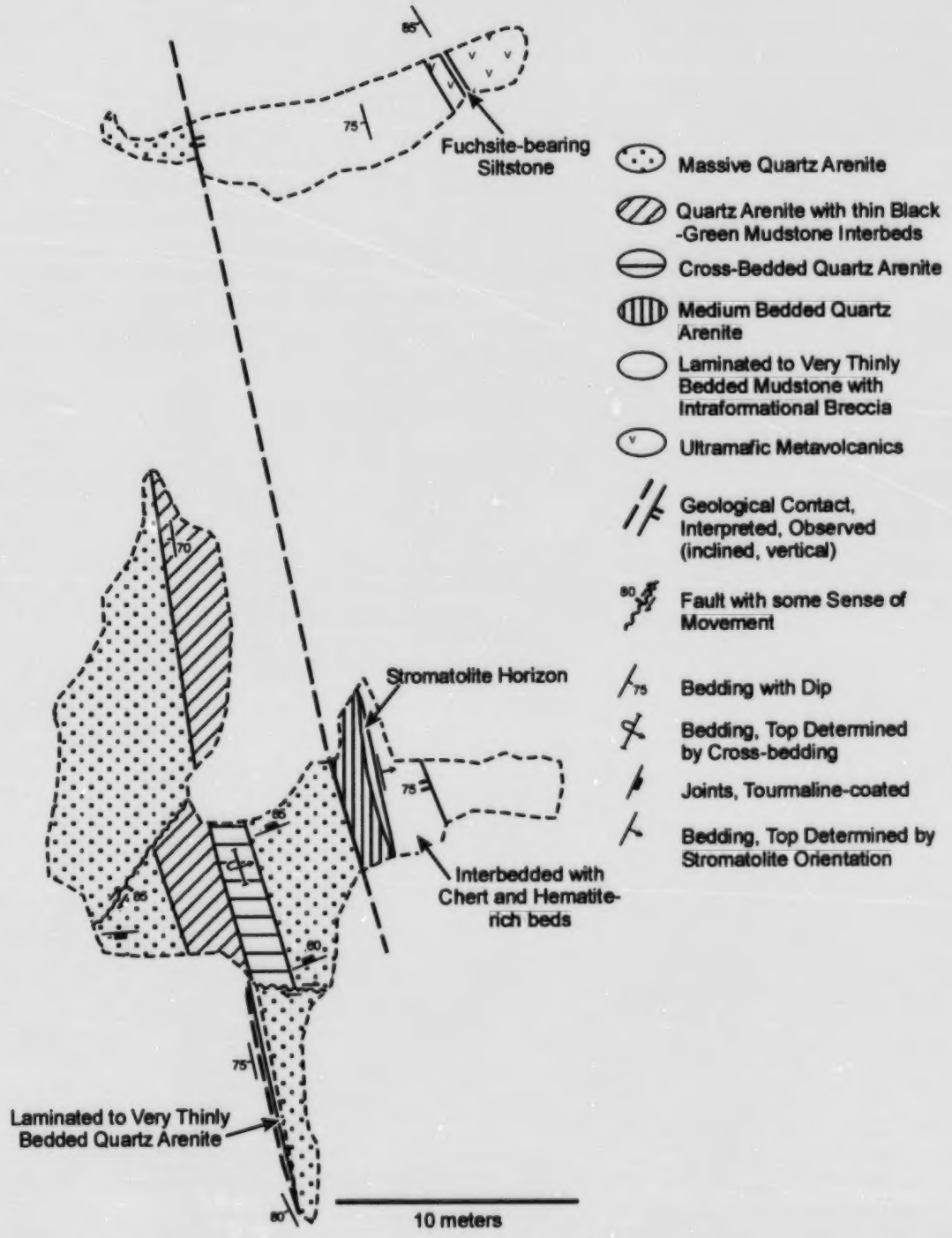

Fuchsite-bearing Siltstone
Stromatolite Horizon
Interbedded with Chert and Hematite-rich beds
Laminated to Very Thinly Bedded Quartz Arenite
10 meters
Massive Quartz Arenite
Quartz Arenite with thin Black -Green Mudstone Interbeds
Cross-Bedded Quartz Arenite
Medium Bedded Quartz Arenite
Laminated to Very Thinly Bedded Mudstone with Intraformational Breccia
Ultramafic Metavolcanics
Geological Contact, Interpreted, Observed (inclined, vertical)
Fault with some Sense of Movement
Bedding with Dip
Bedding, Top Determined by Cross-bedding
Joints, Tourmaline-coated
Bedding, Top Determined by Stromatolite Orientation

Figure 6. Detailed geology of the Keeyask Lake metasedimentary assemblage near Pakiagama Lake.

black and green mudstone laminae that form planar-stratified beds, which are generally laterally continuous for tens of metres. These beds are common along the entire strike length of the KLS.

Framework grain size ranges from 0.1 to 2 mm, with a modal of 0.75 to 1 mm. These metasedimentary rocks reveal a marked bimodality of grain size and a negative skewness (deKemp 1987), indicating a high degree of sorting and a reduced amount of the fine grain fraction. This is a common feature of mature sedimentary rocks deposited in beach environments (Leeder 1982).

Many detrital grains are overgrown with authigenic quartz and are surrounded by a matrix of microcrystalline quartz, chlorite and acicular tourmaline. Occasionally, nonrecrystallized quartz cement fills the original pore spaces between grains. Hornblende and muscovite are minor matrix constituents. X-ray diffraction data suggest that illite also forms part of the matrix (Arias 1986).

Preservation of original grain textures is varied. Near Centre Lake, original detrital grains are difficult to discern because of extensive shearing by the nearby North Caribou River fault, which caused the framework clasts to become indistinguishable from the matrix fraction. At Centre Lake, 2 to 3 mm porphyroclasts of quartz arenite are enclosed by a highly recrystallized and foliated polycrystalline quartz matrix. Preservation of primary grain texture tends to improve markedly to the north of this zone, particularly near Pakiagama Lake (Figure 6). Heavy mineral fractions, forming less than 1% of the quartz arenite, comprise pyrite, magnetite, zircon, tourmaline, apatite, sphene and topaz in order of decreasing abundance. Minor accessory heavy minerals include ilmenite and monazite. Most iron oxides occur as euhedral authigenic crystals, but some are subrounded detrital grains up to 0.5 mm in size. Zircon occurs as <0.05 mm well-rounded grains and as zoned, stubby prismatic euhedral crystals 0.10 to 0.18 mm along the *c*-axis. These euhedral zircons commonly occur as inclusions within detrital framework quartz grains.

Quartz Wacke

These metasedimentary rocks are generally massive and only rarely exhibit depositional structures. Framework grains are rounded to subrounded and show moderate sorting. Matrix fractions are 20 to 30% and are composed of microcrystalline quartz and minor muscovite. Less than 1% by volume is composed of, in order of increasing abundance, accessory detrital grains including apatite, possible rutile, topaz and well-rounded <0.5 mm zircon.

Stromatolitic Mudstones

Columnar, stratiformal and domal stromatolite forms (Photo 4), discovered in 1984 by E.A. deKemp, represent the first known occurrence in the Sachigo Subprovince of Ontario. A detailed study was undertaken by Arias (1986).

Quartz Siltstone

A 5 m thick unit conformably overlies the stromatolitic zone and is composed of 1 to 5 cm interbeds of quartz siltstone and laminated chert. The siltstone is generally graded from a coarse siltstone base to a claystone top. The framework grains, mainly subangular quartz, have a size range from 0.5 to 0.1 mm and comprise only 20 to 25% by volume. The matrix contains extensive recrystallized quartz and minor chlorite and illite.

The laminated quartz siltstone is interbedded with hematite-rich siltstone and finely laminated chert beds. This transition is gradational over a 3 m zone, which is succeeded by lean oxide facies banded iron formation. Intraformational slump breccias supported by a black chert matrix occur directly below and, in some cases, within the iron formation. Clasts within these primary slump structures are angular and have been rotated and dislodged from the underlying laminated mudstone unit.

Photo 4. Stromatolite-bearing bed, intercalated between quartz arenite (QA) and laminated quartz siltstone (S). Note the upward convergence and slight outward radial orientation of the peaked, jacutuphyton-like forms. Same locality as Photo 3.

Banded Iron Formation

The top of the KLS, in most cases, is marked by ferruginous chemical metasedimentary rocks composed of up to 5 m of chert-magnetite banded iron formation, related angular breccia and laminated chert. However, these rocks should not be used as a stratigraphic marker unit in outcrop or drill hole investigations as there is apparent lithologic variation along strike. For example, on the Eyapamikama–Pakiagama lakes portage to the north, the KLS sequence is terminated by a very thinly bedded to laminated, dolomite-rich calcarenite, which contains 5% well-rounded quartz grains. These rocks lie in contact with overlying komatiitic metavolcanic rocks of the KLV.

Well-preserved sections of banded iron formation reveal delicate alternations of magnetite-rich and silica-rich laminae. The silica-rich laminae are cream to clear and occasionally brown on weathered surfaces; magnetite-rich laminae are dark grey to black and are hematite stained. Generally, the bedding pattern in the iron formation occurs on 2 scales:

- alternating silica-rich and magnetite-rich laminae (0.5 to 1 cm thickness)
- internal laminations (millimetre thicknesses) superimposed on the above category as either silica-rich microlayers within magnetite layers or as magnetite and graphitic films within chert layers.

Rare chemical gradation from a silica-rich base to an iron-rich top is observed within the centimetre-scale laminae. Most laminations are laterally extensive to tens of metres. Bedforms within the iron formation indicate a lack of current influence.

Keeyask Lake Metavolcanic Assemblage

DISTRIBUTION

The Keeyask Lake metavolcanic assemblage (KLV) comprises an east-facing, 50 to 1700 m thick metavolcanic sequence, which is traceable from the northwesternmost bay of Eyapamikama Lake south to the North Caribou River, where it is apparently terminated by a major fault.

ROCK TYPES

The lowermost units are dominated by spinifex-textured and polysutured ultramafic flows (Photos 5 and 6), which reveal excellent preservation despite the complete alteration of primary minerals into talc, carbonate, serpentine, actinolite and magnetite. The upper part of the KLV sequence commonly reveals intercalation of basaltic komatiite and minor peridotitic komatiitic rocks at the outcrop scale. The basaltic komatiites (Figure 4) are more typically pillowed than massive flows toward the top of the KLV.

Pillows are generally small (10 to 20 cm length) relative to those in the NRV or SRV. The maximum pillow size is 0.75 by 1 m (Photo 7). The uppermost part of the KLV is featured by gradation from pillows into a 20 m thick zone of *in situ* broken pillow breccia (Photo 8).

Massive flows are dominantly variolitic. These rocks were delineated over a minimum strike length of 5 km and, thus, may represent a useful stratigraphic marked unit. The varioles individually attain a maximum diameter of 5 cm, but may coalesce forming much larger ameboid-like masses. Smaller varioles, less than 1 cm diameter, occur within amygdular mafic metavolcanic rocks.

SIGNIFICANCE OF THE KEEYASK LAKE METAVOLCANIC ASSEMBLAGE

Deposition of these ultramafic to mafic metavolcanic rocks is significant in the evolution of the NCLB and possibly marks a fundamental change from platformal supracrustal stage (AAV, KLS) to those assemblages (KLV, NRV, SRV, OLV, FLV, LLV, ELS) generated during rift phase activity (Groves and Batt 1984). Crustal instability is also suggested by *in situ* breccias composed of laminated to thinly bedded dolomitic clastic metasedimentary rocks (KLS) which lie directly below the komatiitic metavolcanic rocks. These local breccias (Photo 3) may have been produced by seismic activity associated with instigation of the rifting.

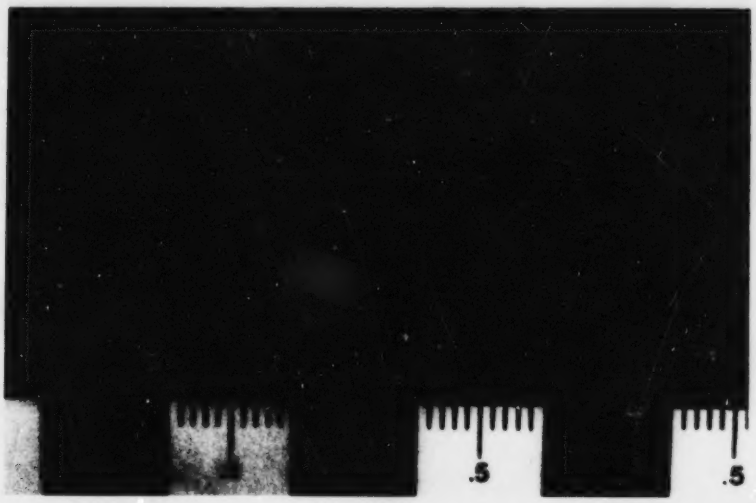


Photo 5. Spinifex-textured komatiitic metavolcanic rock from the Keeyask Lake metavolcanic assemblage (locality J27-1). Note the delicate, dovetail-like disposition of relict olivine blades, now completely replaced by secondary minerals.

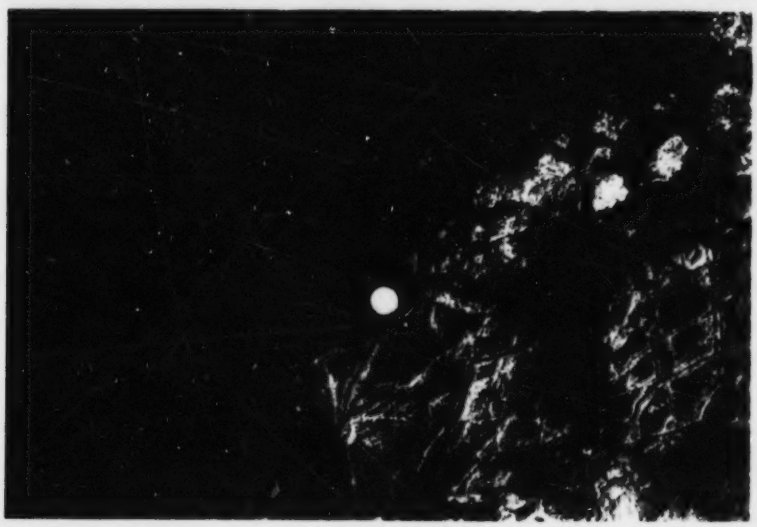


Photo 6. Polysuture structure in komatiitic metavolcanic rocks at locality J30-15. Coin diameter is 2.3 cm.

UNCONFORMITY BETWEEN KEEYASK LAKE METAVOLCANIC AND EYAPAMIKAMA LAKE METASEDIMENTARY ASSEMBLAGES

The contact between the uppermost metavolcanic rocks of the Keeyask Lake section and the basal conglomerates of the Eyapamikama Lake metasedimentary succession is exposed in several localities at low water level along the western shoreline of Eyapamikama Lake. This contact grades from conformable to unconformable. At 1 locality, the contact is well defined and almost razor sharp. Elsewhere, it appears gradational, with interstratified conglomeratic units that incorporated coarse-grained ultramafic to mafic metavolcanic flow breccia. Importantly, a major lithologic change occurs over a short distance, which represents a drastic and rapid environmental change. Because much of the basal conglomerate of the Eyapamikama Lake metasedimentary rocks contains clast populations derived from underlying units, it is probable that a well-developed unconformity was present and may be preserved within the map area.

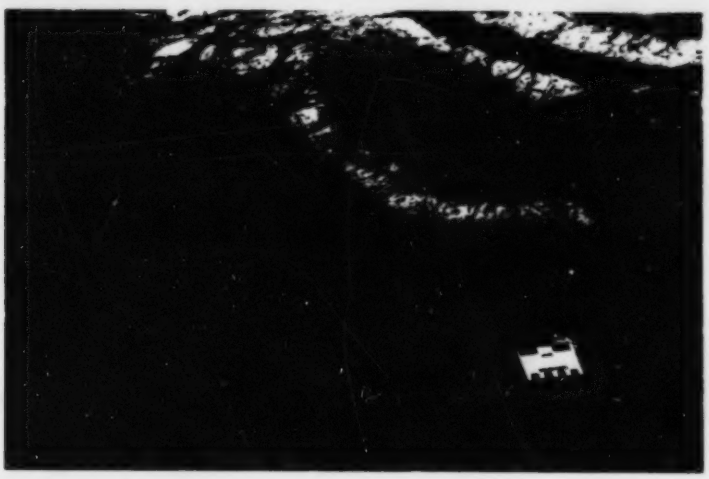


Photo 7. Pillowed mafic metavolcanic rocks from the upper portion of the Keeyask Lake metavolcanic assemblage at locality J30-19.

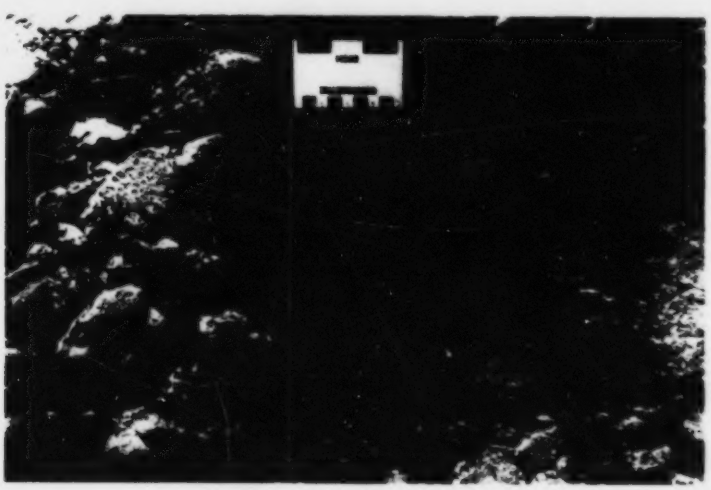


Photo 8. Flow-top breccia in ultramafic metavolcanic rocks in the upper portion of the Keeyask Lake metavolcanic assemblage at locality J30-15.

Lundmark Lake Metavolcanic Unit

DISTRIBUTION

Actinolite-rich, mafic to ultramafic metavolcanic rocks occur in a narrow (0.12 to 0.16 km) strip between the SRV and ELS. Traceable at least 13 km from the southwest end of Akow Lake northward to Eldorado Lake (local name), these metavolcanic rocks occupy a similar stratigraphic position to the KLV in being situated immediately beneath the ELS. The Lundmark Lake metavolcanic unit (LLV) may have even greater strike extension to the northwest, toward Eyapamikama Lake, as suggested by the aeromagnetic continuation of the associated Akow–Eyapamikama lakes banded iron formation in this area of negligible rock exposure. Continuity south of Akow Lake is probably minimal as petrochemical data reveal no komatiitic metavolcanic compositions along the western contact of the ELS between Opapimiskan and Akow lakes.

ROCK TYPES

Mafic and Ultramafic Metavolcanic Rocks

Pillowed, massive, and very local ultramafic metavolcanic breccia units comprise most of the LLV (Photo 9). Pillows are relatively small and moderately flattened compared to those in the Doubtful Lake area, ranging from 3 by 33.5 cm to 8 by 95 cm. Length:width ratios of the pillows vary between 10 and 30. The pillows are homogeneous, deep green on fresh surface, light green weathered surface. No mesoscopically obvious amygdules, variolites, or phenocrysts were noted.

Selvages, which are much narrower compared to those in the SRV, are dark green on weathered surface, vary between 5 to 10 mm in thickness, and are commonly inconspicuous unless accompanied by appreciable carbonate, in which case, coincidence with zones of recessive weathering is apparent.

Ultramafic breccia was encountered at 2 closely spaced localities (Q7-6 and Q7-8). These comprise a 2 to 10 metre wide unit grading into pillowed, ultramafic metavolcanic rocks. The breccia is monolithic and contains approximately 95% fragments, which are moderately flattened and range in size on outcrop surface from 0.5 by 2.5 cm to 4 by 24 cm.

Textures are mainly decussate and nematoblastic. Prevailing grain sizes are less than 1 mm in the metavolcanic sequence with the exception of the subordinate massive porphyroblastic ultramafic units, which are fine to medium grained. Actinolite is the dominant mineral and composes up to 95% of the rock. It is subhedral to euhedral, nonpoikiloblastic, and occurs as interlocking slender grains or in radiating fibrous bundles. Chlorite (from 5 to 20%) occurs in some thin sections, although this mineral is generally absent. Accessory minerals include iron oxide, carbonate, and very rare tourmaline. Titanite was not encountered within these rock types, although it represents a common accessory mineral within the mafic metavolcanic rocks.

Massive, fine- to medium-grained horizons, up to 3 m in width, occur within the pillowed ultramafic metavolcanic sequence. These rocks occur at localities O56-1, Q7-4A, Q7-7B and R10-1B and comprise up to 10% of an exposure. Weathered surfaces are dark green to black, depending upon dominance of actinolite or hornblende.

Mafic metavolcanic rocks intercalated within the ultramafic extrusive sequence consist of pillowed and massive flows and are of normal tholeiitic composition (Figure 4). At locality O56-4, a pillowed flow, 2.6 m in thickness lies in sharp contact with a 1.2 to 3 m wide massive flow. Pillow structures are considerably flattened with length:width ratios up to 140 in outcrop surface.

Chemical Metasedimentary Rocks

The LLV hosts the Akow–Eyapamikama lakes banded iron formation unit, which is one of the most extensive in the NCLB. This silicate-oxide facies unit has an aeromagnetically interpreted strike length of 26 km and maximum magnetic relief of 4250 gammas. The best exposures are situated in the Lundmark Lake area, where iron formation is intercalated with basaltic komatiite rocks situated 120 to 160 m from the regional contact with the ELS. Observed thickness of the banded iron formation varies from 11 to 50 m.

Typically, the banded iron formation is thinly to very thinly bedded and fine grained to locally coarse grained. The latter relates to rare garnet-rich porphyroblastic layers. Ductile deformation commonly interrupts the regular banding of this iron formation by folding, boudinage, and later parallel shear zones (*see* "Structural Geology").

Chert mesobands vary in thickness from 0.5 to 12 cm and, in most cases, comprise 40 to 50% of the rock. However, a wide range is notable, from 10 to 95%. These bands are fine grained, recrystallized, and weather from light grey to milky white. Mafic mesobands range in thickness from 3 mm to 20 cm and consist dominantly of either fine-grained magnetite or grünerite.

Grünerite-rich mesobands, which commonly account for 40 to 45% of the banded iron formation exposures, are distinctive due to their rusty brown to golden brown weathered surfaces. Grünerite (70 to 95%) occurs as fine-grained euhedral to subhedral prisms, which, in some cases, is visible only with aid of a hand lens on clean weathered surfaces.

Photo 9. Relatively large pillows in basaltic komatiite of the Lundmark Lake metavolcanic unit located about 1 km northwest of Akow Lake. Coin diameter is 2.3 cm.

Opapimiskan Lake Metavolcanic Assemblage

Near Opapimiskan Lake, the NRV and SRV progressively taper and are supplanted to the southeast by a distinctly different supracrustal assemblage, named the Opapimiskan Lake metavolcanic assemblage (OLV) (Figure 3). These rocks are particularly important as it forms the host to several significant gold deposits on the Musselwhite property at the West Anticline Zone (Hall and Rigg 1986) and nearby East Bay (local name) of Opapimiskan Lake. The OLV is distributed within a roughly U-shaped regional unit, which is continuously traceable for 65 km northwest from Markop Lake to Opapimiskan Lake and, from there, south to Barrigar Lake before reversing to Zeemel Lake and, finally, striking southeast to the Pipestone River. This bifurcated supracrustal assemblage is bounded to the northwest by a complexly folded contact with the SRV, which is mainly interpolated from aeromagnetic data. To the south and southwest, the OLV lies in contact with intrusive granitoid rocks of uncertain affiliation. Internal greenstone belt contacts mainly involve the ELS, which are macroscopically intercalated with the OLV approximately on a 1:1 basis between Zeemel Lake and the Pipestone River. Width of the OLV unit varies between 0.1 and 1.5 km.

STRATIGRAPHIC CORRELATION

The OLV may be correlative with the FLV, LLV and KLV based upon a similar abundance of komatiitic metavolcanic rocks, a very similar petrochemistry (Figure 4) and presence of significant oxide- and silicate-facies banded iron formation units. However, stratigraphic correlation with these supracrustal assemblages is obviated by spatial separation. If the OLV is contemporaneous with the KLV and signifies rift phase volcanism, it follows that the 5 to 20 m pelitic unit, which structurally overlies the Opapimiskan Lake banded iron formation unit (Hall and Rigg 1986, p.126), could represent a stratigraphic equivalent of the ELS and, hence, could overlie the OLV.

ROCK TYPES

The OLV sequence is overwhelmingly ultramafic to mafic in composition. Silicate- and oxide-facies banded iron formation units are widespread and serve as valuable stratigraphic and structural marker units. Felsic and intermediate metavolcanic rocks are apparently absent.

Mafic and Ultramafic Metavolcanic Rocks

An abundance of komatiitic metavolcanic rocks is the prime characteristic of the OLV. Approximately 90% of analyses shown in the MgO versus Al_2O_3 plot of Figure 4 fall into the komatiite field. The remainder mainly cluster within the normal tholeiite field. A compositional similarity with the KLV, LLV and FLV is also notable.

Primary volcanic structures in the OLV include pillows, pillow breccia, flow top breccia and varioles. These structures are particularly well preserved about 1 km east of Zeemel Lake (OP127-1, OP127-2 and OP127-3). Komatiitic metavolcanic rocks here consist of actinolite-rich, massive, pillowed and variolitic flows. The massive flows are light green, medium grained and may grade into monolithic, angular flow-top breccia (Photo 10). The pillows are emerald green on clean weathered surfaces and are generally small, ranging on outcrop surface from 3 by 9 to 8 by 37 cm. Their selvages are quite narrow (3 to 5 mm) compared to pillows of tholeiitic composition. These typically weather recessively and contain carbonate. Varioles associated with both pillowed and nonpillowed komatiites are common in such rocks

throughout the Zeemel–Libert lakes area. At locality OP 127-2, these occur as singular ellipsoidal ones ranging from 3 by 15 mm to 16 by 65 mm on outcrop surface or as larger coalescing masses.

Spinifex and polysuture textures and hyaloclastitic breccia are rare and restricted to localities proximal to where the OLV crosses the Pipestone River. These variants are apparently confined to komatiites containing greater than 25% MgO and less than 6.5% Al_2O_3 (Figure 4).

Striking hyaloclastite breccia occurs at several localities (Photo 11) in this area, commencing about 1 km north-northwest of the waterfalls shown in Photo 12. More typically, the OLV rocks are highly deformed, medium grained, granoblastic or decussate in texture. They are composed essentially of actinolite with minor plagioclase and chlorite.

In the Opapimiskan Lake area, the OLV is overprinted by a strong D_2 tectonic fabric coupled with extensive shearing. With shearing activity, which is commonly concentrated along or proximal to lithologic contacts with the ELS or subparallel to D_2 axial planes, the komatiites are converted into strongly foliated actinolite-rich units, which, locally, may be talc bearing. Deformation banding occurs locally and can impart a primary bedded appearance to those komatiitic rocks (Photo 13).

Chemical Metasedimentary Rocks

Banded iron formation horizons form significant units within the OLV. These rock types, typically intercalated within komatiitic metavolcanic units, are composed of silicate- and oxide-facies types and may be associated with garnetites and clastic-pelitic metasedimentary rocks.

The Opapimiskan Lake banded iron formation is the most significant in the NCLB in terms of continuity (30 km) and magnetic relief (6500 gammas). It exhibits a complex, contorted macroscopic distribution, which relate to 3 interfering fold generations. This unit has been described in detail by Hall and Rigg (1986) in the context of gold mineralization on the Musselwhite property.

Photo 10. Monolithic, flow-top breccia grades into massive meta-ultramafic metavolcanic rocks at locality OP127-1, which is 1.5 km northwest of Graf Lake.

Previously unmapped grünerite-magnetite-chert banded iron formations, up to 13 m in thickness occur east of Graff Lake. These units, represent a southeastward continuation of a similar sequence on the Musselwhite gold property, and exhibit identical deformation styles (Breaks, Bartlett and deKemp 1985; Breaks et al. 1986; Breaks, Osmani and deKemp 1986) that feature mesoscopic basin-and-dome interference folds (*see* "Structural Geology").

Photo 11. Monolithic, ultramafic metavolcanic breccia of possible hyaloclastite origin at locality BB20-19, 1.2 km northwest of the falls on Pipestone River.

Photo 12. Falls on the Pipestone River, which are controlled geologically by a narrow, resistant, east-striking ridge composed of metagabbro, quartz-rich arenite, conglomerate and minor spinifex-texture komatiitic metavolcanic rocks.

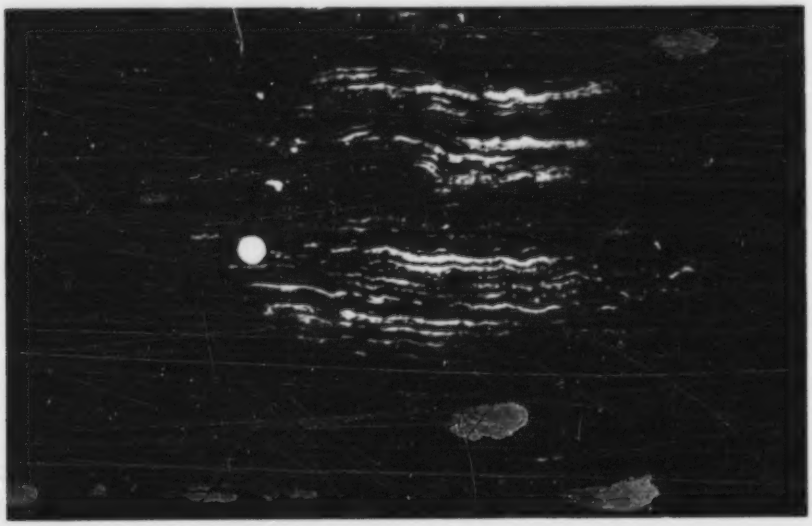


Photo 13. Pseudo-bedding in ultramafic metavolcanic rocks imparted by strong deformation at locality GF-30, 1.9 km east of Graf Lake. Coin diameter is 2.3 cm.

Forester Lake Metavolcanic Assemblage

DISTRIBUTION

The Forester Lake metavolcanic assemblage (FLV), a mafic and ultramafic metavolcanic sequence, occupies the southeastern end of the NCLB (Figure 3). The southern curvilinear contact interdigitates with tonalitic granitoid rocks and exhibits a prominent narrow septum along Boyce Lake. Most of the northern contact is marked by overlying clastic metawacke rocks, metapelites and quartz arenite of the ELS.

ROCK TYPES

Mafic and Ultramafic Metavolcanic Rocks

Dominant units consist of pillowed, massive and amygdaloidal mafic and ultramafic metavolcanic rocks. Although komatiites are difficult to recognize in the field, most of the analyses from the FLV indicate that komatiitic rocks are actually more common than tholeiites (Figure 4). Magnesium oxide (MgO) contents reach a maximum of 21.1%, and Al_2O_3 contents diminish to 5.32%. The apparent difficulty in the recognition of komatiites in the FLV is, in part, a reflection of the widespread conversion of such rocks into amphibolites. Good exposures near the western end of Forester Lake and within the Boyce Lake septum exemplify such amphibolites. These rocks are dark green to black, highly lineated and commonly pillowed. Pillow structures measure 2.5 by 168 cm to 9.5 by 38 cm in sections normal to the stretching lineation. The long dimension is not usually measurable.

Calc-silicate pods are widespread in the amphibolitic metavolcanic rocks near Forester Lake. These ovoid to irregular masses, which range from 2 by 2.5 cm to 12 by 18 cm, are composed of a fine-grained aggregate of diopside, epidote, plagioclase and minor quartz and garnet. Such masses occur within pillows or spatially associated massive flows.

Hornblende porphyroblastic, medium- to coarse-grained, mafic and ultramafic metavolcanic rocks occur widely in the Sage Lake area. These medium- to coarse-grained, subtly lineated rocks may be confused with metamorphosed mafic plutonic rocks (e.g., Robertson 1941). However, their intercalation with grünerite-magnetite chert banded iron formation and widespread pillow structures provide evidence of their volcanic origin.

At Neawagank Lake, the metavolcanic rocks are dominantly composed of fine- to coarse-grained mafic pillowed and massive flows. Massive to weakly foliated, coarse-grained flows either represent flow centres or subvolcanic intrusions. Relatively highly deformed mafic metavolcanic rocks mapped as amphibolite were encountered close to the contact with plutons in the southern margins of the belt, and on the northwestern shore of Neawagank Lake.

Two felsic metavolcanic units were mapped in this sequence. One quartz-rich fragmental unit, which is 60 m thick, is located about 200 m northwest of Wesley Lake. The other unit, located 250 m north of the western shore of Neawagank Lake, is a 3 m thick subvolcanic unit interbedded with pillowed mafic metavolcanic rocks.

Chemical Metasedimentary Rocks

Though rarely exposed, iron formation is widely distributed in the FLV as is evidenced by several strong magnetic anomalies. The magnetic relief ranges between 1300 and 2100 gammas (Ontario Geological Survey 1985). The magnetic patterns, especially in the Sage and Neawagank lakes area, infer that the iron formation is complexly folded and faulted in several places. In the Neawagank Lake area, for example, 2 major bands of iron formation (maximum magnetic relief = 2000 gammas), which strike northeastward, were inferred from aeromagnetic maps (Ontario Geological Survey 1985). The first band, which has a strike length of approximately 1.5 km, lies just south of Wesley Lake. The second band is situated immediately north of the western shore of Neawagank Lake. The exposed length of this band is 5 km. The southwestern extension of the second band appears to be complexly folded and sheared in several places.

Several other narrow, discontinuous iron formations bands (maximum magnetic relief = 1670 gammas), probably enclosed in metavolcanic rocks, are situated approximately 3 km north of Norbury Lake.

Exposures of banded iron formation are rare in the FLV. About 1 km northwest of the northernmost bay of Forester Lake, a 15 m thick, laminated to very thinly bedded magnetite-chert banded iron formation is intercalated with komatiitic metavolcanic and pillowed mafic metavolcanic rocks. Layers of garnet-actinolite-chlorite resemble those in chemical metasedimentary rocks on the Musselwhite property.

Just north of Sage Lake, folded grünerite-magnetite-chert iron formation, approximately 12 m thick, enclosed in hornblende-porphyroblastic mafic and ultramafic metavolcanic rocks is exposed over a length of 100 m.

South Rim Metavolcanic Assemblage

DISTRIBUTION

The South Rim metavolcanic assemblage (SRV), a mafic to felsic metavolcanic sequence, which is traceable for about 95 km from Wapikiskapia Lake to the Paseminon River, defines the southern to western edge of the NCLB (Figure 3). It lies in continuous contact with the North Caribou Lake batholith and varies in width from 0.4 to 5 km.

STRATIGRAPHIC AND TEMPORAL RELATIONS

Stratigraphic relations of the SRV with the other major supracrustal assemblages can only be unravelled for the ELS, which consistently overlies the SRV. Age relations with the AAV and KLV could not be established due to a major brittle–ductile deformation zone (North Caribou River fault).

Equally tenuous are stratigraphic relations with the OLV, since this contact is mainly beneath Opapimiskan Lake and situated within a domain of high ductile deformation. In this area, the SRV is interpreted to progressively attenuate, within a zone of increasing strain, somewhere between this lake and the Paseminon River.

The SRV demonstrably predate emplacement of the North Caribou Lake batholith at 2870 Ma. This is indicated by the common occurrence of mafic metavolcanic xenoliths and an amphibolite contact metamorphic aureole imposed upon the generally low-grade SRV.

ROCK TYPES

Mafic Metavolcanic Rocks

The SRV sequence is dominated by low-grade, pillowed and massive flows, which are commonly normal to magnesium-tholeiitic in composition (Figure 4). Pillowed flows are widespread in strong contrast to the AAV and are particularly well preserved between Stanton Lake and Akow Lake. Good exposures occur at Doubtful Lake and along the narrows connecting Seeseep Lake with Eyapamikama Lake. Here, slightly deformed pillows range from 0.3 to 4 m in length, average less than 1 m and consistently indicate north- to northeast-facing stratigraphy. Length:width ratios are commonly between 2:1 to 12:1.

A well-exposed cross section of the South Rim sequence is afforded along the channel between Eyapamikama and Seeseep lakes. These pillowed flows are intercalated, on the scale of metres to tens of metres, with less abundant massive mafic flows. Some pillowed sections include pillow breccias and rare hyaloclastite.

Pillowed flows tend to display a wide diversity of character from one flow to the next, even across single outcrops. This is particularly evident with respect to variations in strain state exhibited in these rocks. The spectrum from virtually undeformed to highly sheared rocks is represented, even across single outcrops. In the area of the Seeseep Channel several thin, discrete shear zones are mineralized, with significant gold values (*see* "Economic Geology"). These shear zones may have followed hyaloclastite zones, which, where recognizable, have acquired considerable strain.

In the area east of Doubtful Lake, near the contact with the Eyapamikama Lake metasedimentary assemblage, pillowed flows are abundant, but are locally difficult to recognize due to alteration patterns, including biotite enrichment of selvages and intense carbonatization. The nonfoliated to strongly foliated pillowed and massive mafic flows consist essentially of 55 to 90% hornblende (partially altered to actinolite) and interstitial microcrystalline plagioclase aggregates.

South of Akow Lake, rocks originally mapped as fine-grained actinolite-chlorite schists (unit 2m in Breaks et al. 1986) microscopically consist of hornblende poikiloblasts and finely recrystallized plagioclase.

Massive and pillowed mafic flows in the Seeseep–Doubtful lakes area are commonly aphanitic to fine grained and nonfoliated to moderately foliated. Variably foliated medium-grained mafic rocks may, in some cases, represent the central parts of individual flows. Plagioclase-phyric mafic flows, some with phenocrysts up to 2 cm across, are rare. Throughout the South Rim sequence, small, local shears have converted parts of mafic flows to strongly foliated zones in which original features are no longer recognizable. Mafic flows are medium to dark grey to grey-green on the fresh surface, and weather to a variety of colours, most commonly dark grey-green and medium grey. The mafic rocks consist essentially of amphibole (actinolite and/or hornblende), plagioclase and chlorite.

Relict subophitic textures are commonly discernible in low-grade pillowed mafic metavolcanics. This is characterized by 10 to 15% slender, plagioclase laths embedded within an entirely metamorphosed matrix, now dominantly hornblende. The anhedral plagioclase laths are randomly oriented, typically 0.04

by 0.34 mm, with a maximum size of 0.15 by 0.27 mm. Grain boundaries of the plagioclase laths are typically overgrown by hornblende.

An increase in deformation and metamorphism is apparent in the SRV south of Akow Lake. This is evidenced by increasingly penetrative foliations and by the greater number of discrete, mappable shear zones. Pillow structures become progressively more attenuated and coupled with medium-grade regional metamorphism, these structures generally are of little use here in stratigraphic analysis. For example, along the western shoreline of Opapimiskan Lake length:width ratios of pillows are commonly between 20 and 35. The paucity of recognizable pillows west of Staunton Lake may be due, in part, to the higher state of strain imparted by deformation in proximity to the North Caribou Lake fault.

Pillow interiors are dark green to black on weathered and fresh surfaces, fine grained and dark grey-green to black on clean weathered surfaces. Thickness of pillow selvages varies between 2.5 and 25 mm. The selvages are commonly separated by accumulations of secondary minerals, composed mainly of quartz, carbonate and augmented by epidote and tremolite-actinolite. These masses can be up to 0.3 m in width and particularly congregate in the triple-point junctions between neighbouring pillows. Cavities are commonly apparent due to dissolution of carbonate masses. In areas of higher metamorphic grade, pillow interiors may be overprinted by medium- to coarse-grained hornblende porphyroblasts similar to pillowed flows found in the Sage Lake area.

Subhedral plagioclase phenocrysts (<1 to 3 by 5 mm) comprise up to 5% within some pillows and tend to concentrate toward the pillow centres. Although generally rare in SRV pillows, amygdules may also be subtly evident as, for example, at locality L58-1. Ovoid-shaped amygdules up to 0.8 by 1.4 mm are brown in plane polarized light and consist of an anhedral, aggregate of clinozoisite and epidote (80%), quartz (10%), carbonate (5%) and opaque iron oxide (5%), in which the grain size ranges from 0.1 to 0.3 mm.

Felsic and Intermediate Metavolcanic Rocks

Felsic and intermediate flows, pyroclastic units and hypabyssal equivalents are widely distributed throughout the SRV sequence. Regionally, these comprise only a few percent of the supracrustal assemblage and occur mainly in thin localized units, typically less than 10 m in thickness. The most extensive unit (200 by 600 m) is situated along the western shoreline of Opapimiskan Lake and is composed of intermediate tuff, lapilli tuff, heterolithic tuff breccia and rare felsic flows.

Chemical Metasedimentary Rocks

Banded iron formation is rare in the SRV and the most extensive is the Akow–Eyapamikama lakes banded iron formation, which is hosted by the Lundmark Lake metavolcanic unit (LLV). No exposures of the Doubtful Lake banded iron formation (aeromagnetically inferred strike length = 7 km) are known, although diamond drill intersections were made by Eldorado Nuclear Limited (assessment files, Resident Geologist's office–Thunder Bay North, Thunder Bay, Ontario).

Smaller units occur in the SRV 0.8 km north of Staunton Lake where a lean quartz-magnetite iron formation is exposed. This unit coincides with a weak curvilinear aeromagnetic anomaly of 800 gammas relief (Ontario Department of Mines–Geological Survey of Canada 1960, Map 919G). Chert bands, 2 to 3 mm thick, comprise most of the rock and consist of a granoblastic network of quartz grains 0.05 to 0.1 mm across. Fine-grained mafic layers, 3 to 5 mm thick, consist mainly of poikiloblasts and slender grains of hornblende, with 10 to 15% fine magnetite, and accessory magnetite.

North Rim Metavolcanic Assemblage

DISTRIBUTION

The North Rim metavolcanic assemblage (NRV), which is dominated by mafic metavolcanic rocks, forms the north to eastern edge of the NCLB stretching for 97 km from Atikomik Lake in the west to Opapimiskan Lake (Figure 3). Width of this sequence varies between 0.4 and 2.6 km. Continuity beyond Opapimiskan Lake could not be established, however, it is postulated that the NCLB in this area is either truncated by major shear zones or is markedly attenuated in a southerly direction. Physiographically, the NRV forms a resistant, generally continuous, slightly elevated rounded ridge, in which local relief may reach 20 m, north of the western end of Eyapamikama Lake.

A narrow, poorly exposed unit of ultramafic and mafic metavolcanic rocks appears to define the northeastern contact of the North Caribou Lake belt between Opapimiskan Lake and Pipestone River. This unit, which has a width of approximately 400 m, has mainly been delineated on the basis of aeromagnetic data (Ontario Geological Survey 1985). A conspicuous curvilinear aeromagnetic pattern is related to magnetite-bearing komatiitic metavolcanic rocks (24.9% MgO, 10.7% total Fe as Fe_2O_3 , and 5.4% Al_2O_3), which are poorly exposed 2 km east of Opapimiskan Lake. The high MgO content of this unit suggests a closer affiliation to metavolcanic rocks of the Opapimiskan Lake metavolcanic assemblage than to the North Rim metavolcanic assemblage, which does not exhibit such elevated MgO contents (Figure 4).

STRATIGRAPHIC AND TEMPORAL RELATIONS

The NRV lies in almost continuous contact with the stratigraphically overlying ELS (Figure 3). In the Atikomik–Miskeesik lakes area, where the ELS sequence terminates, the southern boundary is defined by intrusive contact with the Weagamow batholith.

The contact between the North Rim metavolcanic assemblage and the clastic and chemical metasedimentary rocks of the ELS appears, in many places, to be gradational over a distance across strike of up to 100 m. This is well exemplified in the Castor–Pollux lakes area and is further complicated by a 200 m wide superimposed ductile shear zone (North Rim fault). This gradation is manifested as decimetre- to decametre-scale interdigitation of metawacke, metapelite and/or chert-iron formation with fine-grained, layered or uniform mafic rocks consisting mainly of hornblende and plagioclase. The latter rocks are interpreted to be flow material and/or tuffs, or their minimally reworked equivalents.

A similar lithologic gradation is evident along a series of unnamed lakes 7 km north of Opapimiskan Lake, which is also overprinted by an important brittle–ductile deformation zone (Akow Lake fault). A narrow, 12 km long unit of mafic metavolcanic rocks is enclosed entirely within the Eyapamikama Lake metasedimentary assemblage north of the west half of Eyapamikama Lake. This unit trends parallel to, and is here considered to be part of, the North Rim sequence. Two mafic metavolcanic lenses north of Stanley Lake may be eastern extensions of this unit.

The contact with tonalitic rocks of the Schade Lake gneissic complex to the north is generally not exposed and marked by an abrupt physiographic break. However, near Atikomik Lake, a sharp intrusive contact with biotite tonalite was observed overprinted by a strong cataclastic fabric. Common occurrences of protomylonite tonalites to the east and southeast at de Blicquy, Schade, Ericksen and Dinnick lakes suggests a continuous cataclastic deformation zone, which was apparently controlled by the external

contact of the NRV. Enclaves of mafic metavolcanic rocks are common in the intrusive body to the north, indicating that the extrusion of the North Rim metavolcanic rocks predated the intrusion.

ROCK TYPES

Mafic Metavolcanic Rocks

Mafic metavolcanic rocks, generally of tholeiitic composition (Figure 4), predominate in the NRV. Felsic and intermediate metavolcanics are even scarcer than in the SRV and were noted in only 2 localities.

The North Rim mafic metavolcanic rocks have been pervasively subjected to intense ductile deformation and overprinted by medium-grade regional metamorphism. This is revealed by a penetrative foliation and lineation coupled with pervasive mesoscopic fold development and boudinage. Consequently, preservation of primary textures, structures and readily mappable features is exceedingly poor.

Mafic metavolcanic rocks of the North Rim include mainly massive and pillowed flows. Mafic rocks displaying millimetre- to centimetre-scale layering occur locally. Amygdules or vesicles are common in some pillowed flows, but were rarely observed in nonpillowed flows. Porphyritic flows are markedly absent in the North Rim metavolcanic sequence.

Flow thicknesses are impossible to estimate. Pillows are generally moderately to highly deformed (Photo 14) and range in length from 40 to 125 cm. Length:width ratios vary from 2:1 to 125:1. Selvages range from 0.5 mm to 4 cm thick and average 1 cm. These are conspicuous as dark green to black hornblende-rich domains, which can be garnetiferous locally. Pillow shape and packing arrangement can only rarely be used with confidence to discern stratigraphic tops, as in the McGruer Lake area (*see also* Satterly 1941, p.13).

Photo 14. Strongly deformed pillows in mafic metavolcanic rocks of the North Rim metavolcanic assemblage located at the northwestern end of Hatch Lake.

Vesicles or quartz and carbonate amygdules occur within pillows where they may constitute up to 10% of the rock. Some pillows display a concentric zonation of vesicles and/or amygdules. The ubiquitous presence of pillows containing 10% or more amygdules suggests that the prevailing environment of deposition of the North Rim metavolcanic assemblage was shallow subaqueous.

Most massive and pillowed flows are fine grained, with aphanitic and medium-grained varieties subordinate. The mafic flows are medium green-grey to black, medium green to green-grey to brown-grey weathering rocks composed mainly of hornblende and plagioclase. Other, minor ferromagnesian minerals, which occur in addition to hornblende, are diopside in the Atikokan–Capella lakes area, biotite in the area north of the western end of Eyapamikama Lake, and chlorite in the Castor–Pollux lakes area. The rocks are massive to variably foliated. Moderately to strongly foliated rocks are ubiquitous, but are particularly notable in certain parts of the North Rim, such as the Castor–Pollux lakes area.

Microscopically, the massive and pillowed mafic flow rocks typically consist of xenoblastic to subidioblastic grains of pale to dark green hornblende, averaging 1 mm in length, with interstitial plagioclase recrystallized to form a granoblastic texture, or less commonly, a complex mosaic of fine subgrains. Recrystallization has been complete in nearly all the rocks.

North Rim metavolcanic rocks are commonly layered. Centimetre- to decimetre-wide light yellow-green epidote-rich, light grey-green diopside-rich, and/or black hornblende-rich layers typically alternate with fine- to medium-grained nematoblastic hornblende-plagioclase amphibolitic layers. Tight to close mesoscopic, disharmonious Z-folds with near vertical axial planes and pervasive, southeast-trending, shallowly plunging hornblende lineation deform this gneissic layering. Representative localities containing layered mafic metavolcanic rocks occur in the Hatch Lake, Ericksen Lake and Schade Lake areas.

HORNBLENDE-PORPHYRITIC MAFIC METAVOLCANIC ROCKS

These fine- to coarse-grained inequigranular rocks are widespread in the NRV. In genera, these rocks correlate with domains of higher grade metamorphism and severe tectonic deformation in the NCLB. They also occur widely in the Opapimiskan Lake volcanic and Forester Lake supracrustal assemblages.

As typified by the Hatch Lake area, such mafic metavolcanic rocks are composed of fine- to medium-grained nematoblastic aggregates of hornblende (70%), plagioclase (30%) and accessory quartz and iron oxide.

Hornblende is anhedral to subhedral, porphyroblastic, with ragged grain boundaries and low percentage of inclusions.

Minor Rock Units

Minor units intercalated within the North Rim mafic metavolcanic rocks include possible silicate-facies banded iron formation, dolomitic metasedimentary, felsic to intermediate metavolcanic, possible ultramafic metavolcanic and peculiar, rare cordierite-cummingtonite clastic metasedimentary rocks.

ULTRAMAFIC ROCKS

These rocks of uncertain affiliation occur in a few localities within the NRV, viz. the Akow Lake area, near Hatch Lake, and east of Atikomik Lake. Spatially, such rocks tend to occur immediately adjacent to the regional contact with ELS. Field relations do not permit deductions as to whether such rocks represent

ultramafic flows or intrusive rocks. However, in the case of Akow Lake examples, the striking mineralogical, textural and petrochemical similarities of ultramafic rocks at locality Q7-17 to massive ultramafic metavolcanic flows in the nearly Lundmark Lake metavolcanic assemblage (localities Q7-4A, Q7-7B) suggest a common genesis.

Characteristics of these rocks include a massive appearance, slight porphyroblastic, fine- to medium-grained, decussate texture, and dark green to black hues on fresh surfaces. The colours vary according to relative amounts of black hornblende and green actinolite, either of which can attain maximum levels of 90%. Accessories include plagioclase, biotite and opaque iron oxides.

FELSIC AND INTERMEDIATE METAVOLCANIC ROCKS

In the NRV, these rocks are relatively rare. The only significant accumulation is located 600 m northeast of Hatch Lake, where a 200 by 900 m mass occurs concordant to foliation. Foliated to gneissic, fine-grained, light brown weathering, possible recrystallized tuffs represent the major rock type. Subordinate, intercalated mafic metavolcanic units, typically 0.5 to 4.5 cm and up to 2 m thick, compose up to 20% of an exposure. The felsic to intermediate metavolcanic unit typically occurs in bands 1 to 11 cm in width, although more homogeneous portions can occur such as found near the northwestern limits of the unit.

SILICEOUS AND FERRUGINOUS CHEMICAL METASEDIMENTARY ROCKS

Lean banded iron formation and local chert units occur widely within the NRV sequences. Banded iron formation, however, apparently exhibits a proximity to the contact between the North Rim metavolcanic and the Eyapamikama Lake metasedimentary assemblages. West of McGruer Lake, these units are distributed discontinuously over a strike length of 22 km. A second significant banded iron formation horizon is aeromagnetically traceable for 18 km between Hatch Lake to a point 2 km east of Lundmark Lake.

In the McGruer–Castor lakes area, 5 different localities contain banded iron formation, verified either in the field or inferred from aeromagnetic data (Ontario Department of Mines–Geological Survey of Canada 1960, Maps 909G and 919G). The maximum relief of the aeromagnetic anomalies varies from 1500 to 2500 gammas. At Castor Lake, grünerite-quartz banded iron formation has a corresponding weak linear aeromagnetic anomaly with a maximum relief of less than 1000 gammas.

Specifically, banded iron formation units occur as 6 known tectonic lenses contained within a ductile-deformed mélange including clastic metasedimentary, mafic metavolcanic, sheared possible felsic metavolcanic, carbonate metasedimentary and possible ultramafic metavolcanic rocks. Individual lenses are traceable along strike for 125 m and attain a maximum width of 13 m. One banded iron formation unit, 200 m south of the east end of Pollux Lake, contains 4, fine- to medium-grained, laminated black metapelite interbeds up to 0.6 m thick. This particular unit has been studied in detail by McLarty (1985).

On Castor Lake, an 8 m thick exposure of grünerite-quartz banded iron formation is well exposed near the southwestern end of the lake. This iron formation lies in contact with laminated, fine- to medium-grained feldspathic arenite and garnetiferous mafic mineral-rich, clastic metasedimentary rocks. The thinly to very thinly bedded unit exhibits the effects of considerable tectonic flattening as indicated by isoclinal S-folds in bedding (Photo 15). Chert-rich layers, which comprise about 70% of the unit, are commonly 2 to 6 cm thick, and range to 16 cm thick. Fine-grained grünerite is concentrated in orange to brown weathering layers up to 4 cm in thickness. Accessory garnet and/or black tourmaline is visible in some grünerite layers. Fine-grained tourmaline is evident in veins up to 0.5 cm wide, essentially concordant to layering.

Exposures of the Hatch Lake banded iron formation are very rare and restricted to localities near its northern and southern terminations. All of these exposures suggest that the Hatch Lake unit is mainly of silicate-facies type. On the southwestern shoreline of a small, unnamed lake 685 m northeast of Hatch Lake, a banded iron formation unit with a 10 m thickness is exposed. This unit is enveloped within black, intensely lineated, fine- to coarse-grained hornblende-porphyroblastic amphibolite and dark green, gneissic highly folded, diopside-hornblende mafic metavolcanic rocks.

About 80% of the unit consists of chert bands varying in width from 1.3 to 4 cm. These layers are milky white on weathered surface, recrystallized, and may exhibit local internal laminations. Light grey-green, fine- to medium-grained, diopside-rich layers, 1 to 2 cm in width, comprise the remainder of the banded portion of these chemical metasedimentary rocks. These decussate-textured mafic mesobands consist mainly of diopside and carbonate commonly accompanied by sparse iron oxide. Secondary cummingtonite is occasionally evident as extension gash infillings in boudin necks. Garnet-rich layers associated with considerable rust-staining occur locally toward the southwestern contact.

CARBONATE METASEDIMENTARY ROCKS

These rock types are rare and confined to 3 localities in the Castor–Pollux lakes area and 1 locality near Hatch Lake. In the former area, these occur within a complexly deformed, medium-grade, clastic metasedimentary–mafic metavolcanic-banded iron formation sequence. These rocks are typified by an exposure, near the southwestern end of Castor Lake, which consists of a 20 m thick sequence of carbonates with intercalated arsenopyrite-garnet-biotite metapelite horizons up to 10 cm thick.

The metamorphic assemblage suggests the reaction:

$$\text{dolomite} + \text{quartz} + H_2O = \text{calcite} + \text{tremolite} + CO_2$$

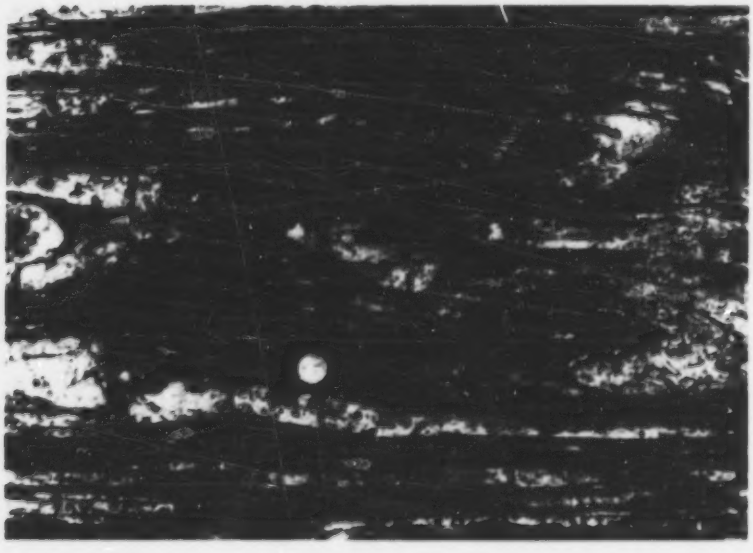


Photo 15. Deformed, isoclinally folded grünerite-chert banded iron formation at locality G32-14, near the southwestern end of Castor Lake. Coin diameter is 2.3 cm.

Eyapamikama Lake Metasedimentary Assemblage

DISTRIBUTION

Clastic metasedimentary rocks, composing the Eyapamikama Lake metasedimentary assemblage (ELS), represent the youngest supracrustal rocks of the NCLB and one of the most extensive assemblages in the NCLB. The ELS occupies the medial portion of the belt and is continuous for the virtually the entire length of the NCLB (Figure 3), a distance of 20 km. These metasedimentary rocks are only postdated by rare fluorite-bearing peraluminous granitoid dykes, pre-D_2 metagabbro dikes and diabase dikes of possible Early Proterozoic age.

ROCK TYPES

Generally, the stratigraphy of the ELS reflects a fining-upward sequence in which basal alluvium and fan delta conglomeratic cycles grade vertically and laterally into finer grained metasedimentary rocks.

Conglomerates

Conglomerates are predominantly restricted to the basal part of the ELS (Photo 16). Most coarse conglomerates of this sequence probably accumulated during a specific phase of regional-scale deposition.

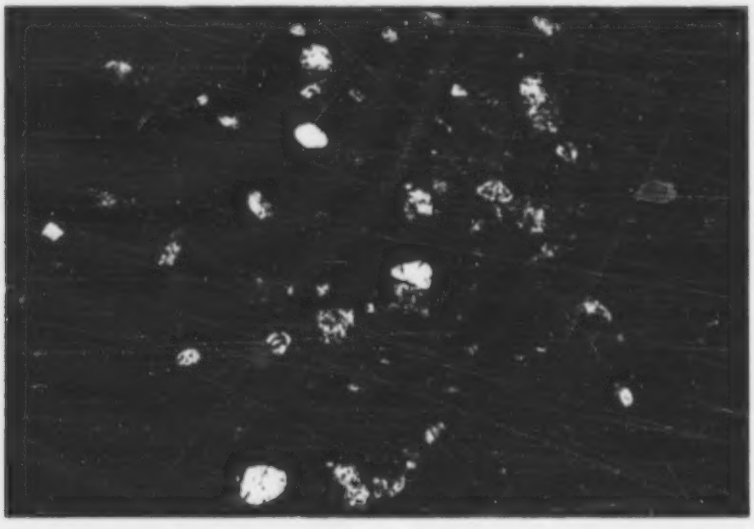


Photo 16. Clast-supported, polymictic boulder conglomerate situated near the southeastern shore of Keeyask Lake at locality J30-1. Note the high percentage of essentially undeformed tonalite clasts. Hammer is 40 cm long.

Clasts within the conglomerates are representative of the main underlying rock types. This includes felsic metavolcanic rocks similar to those of the Agutua Arm assemblage, ultramafic and variolitic mafic metavolcanic rocks of the KLV and laminated quartz arenites and banded iron formation identical to those of the KLS (Photo 17). A high percentage of trondhjemite-tonalite-diorite clasts closely resemble nearby intrusive rocks of the Weagamow batholith (*see* "Intermediate and Felsic Intrusive Rocks"). These clast types occur in conglomerates throughout the NCLB from the extreme eastern portion of Eyapamikama Lake through to north of Seeseep Lake, and also south of Castor–Pollux lakes and in all coarse conglomeratic metasedimentary rocks on the shores of western Eyapamikama Lake. Some clasts reveal a wide variety of compositions and textures and identification in highly strained areas is partly dependent upon subsequent investigation of polished slabs and thin sections.

In the Eyapamikama Lake area, matrix-supported and clast-supported conglomerates and arkosic wackes overlie a range of metavolcanic rocks that form the KLV. The latter include spinifex-textured and polysutured komatiites, variolitic and pillowed mafic metavolcanic rocks and mafic autoclastic breccia. Basal metasedimentary rocks, which directly overlie these metavolcanic rocks, are varied in grain size and composition. These metasedimentary rocks exhibit lateral facies changes that range from coarse matrix-supported polymictic cobble to boulder conglomerates to an angular, oligomictic mafic and ultramafic metavolcanic breccia (Photo 18).

Bed forms in these metasedimentary rocks include basal scours with infilled lag deposits, graded beds and inversely graded beds with stratified pebbly beds. Locally, clasts locally show imbrication within clast-supported conglomerates, such as those at the southeastern shoreline of Keeyask Lake. However, the conglomerate clasts generally tend to be chaotically arranged and matrix supported, with a high sand-sized matrix component (>50%).

Arkosic Arenites

Arenites (<15% matrix) are not common within the ELS. These rocks tend to be restricted to narrow interbeds within predominantly wacke-mudstone-turbidite sequences. Such arenites are invariably plagioclase rich (>50% of framework grains) and most contain more than 10% matrix. Framework grains

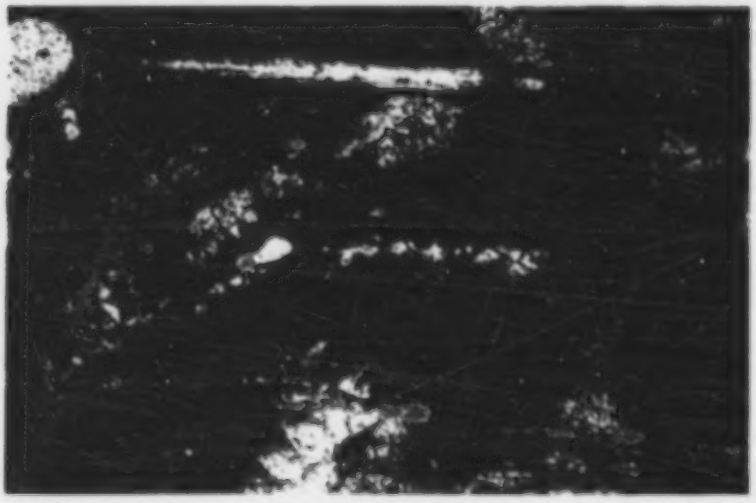


Photo 17. Banded iron formation clast (centre) within basal conglomerate of the Eyapamikama Lake metasedimentary assemblage at locality J27-6. Hammer is 40 cm long.

are texturally similar to the enclosing wackes, showing a range of nonsorted grain sizes, angularity of grains (especially plagioclase) and a lack of lamination. In hand specimen, the arenites are difficult to distinguish from wackes. At higher metamorphic grades, the wackes show a greater content of biotite than the arenites. Arkosic and subarkosic arenites are confined to the western end of Eyapamikama Lake, and are commonly minor constituents in proximal conglomeratic submarine fan deposits.

In general, the arenaceous rocks of the Eyapamikama Lake area, other than quartz arenites of the Keeyask Lake metasedimentary assemblage, due to a decrease in the matrix fraction, are considered as marginal extensions of the more common wackes into the arenite field. When other features such as grain composition, angularity and sorting are taken into account, arkosic and subarkosic arenites are quite similar to the arkosic and subarkosic wackes in the area.

Arkosic and Subarkosic Wackes

Arkosic wackes in the map area are abundant along the shores and islands of the western end of Eyapamikama Lake. They occur in close association with the subarkosic wackes, which are essentially identical in hand specimen (Photo 19) with the exception of a higher quartz content. Arkosic and subarkosic wacke is also the main matrix constituent of pebble to boulder conglomerates in the western Eyapamikama Lake area.

The matrix fraction of this rock type ranges from 25 to 60% by volume. Chlorite, muscovite, biotite, carbonate, microcrystalline quartz and plagioclase are the major matrix constituents. Modes of matrix content commonly are difficult to estimate due to the extensive sericitic alteration of plagioclase grains, rendering some indistinguishable from the matrix.

Framework grains (sand-size fraction) are poorly to very poorly sorted and are angular to subrounded. Rounded titanite and well-rounded quartz grains occur as minor constituents in the framework. Because these rocks, by definition, contain less than 20% labile rock fragments, all sand-size chert has been included in the quartz fraction. In some cases, chert contributes more than 10% to the rock volume. Rare euhedral zircon prisms (0.025 by 0.005 mm) occur as inclusions within large sand-size

Photo 18. Ultramafic metavolcanic breccia forms a jigsaw-like clast configuration with a meager matrix of quartz wacke at locality J27-6, which is situated 0.45 km from the northwesternmost bay of Eyapamikama Lake.

grains of phanerocrystalline quartz. Some large, recrystallized quartz grains contain small epidote inclusions. Doubly terminated clear quartz grains and embayed or resorbed quartz grains occur in arkosic wackes. Plagioclase grains are invariably of albite composition, although oligoclase predominates north of Eyapamikama Lake, where the metamorphic grade is higher. One zoned plagioclase grain, which displayed intense sericitic alteration within the centre of the grain, was noted, suggesting a more calcic core.

Most wackes are preserved as massive beds ranging in thickness from 1 cm to 2 m. Rare bedforms associated with these rocks include large cross-trough stratification (festoon bedding) and grain gradation (Photo 20). Small-scale (<1 cm) flame structures, load casts and grain gradation are more common within 1 to5 cm wacke interbeds of the mudstone–wacke couplets along the Eyapamikama Lake shoreline. These rhythmic metasedimentary rocks are interpreted as turbidites that formed in medial- to distal fan-environments. Arkosic and subarkosic wackes are common as the matrix to both the matrix-supported and clast-supported polymictic pebble to boulder conglomerates.

Lithic Arkosic and Subarkosic Wackes

These rocks occur in association with previously mentioned arkosic and subarkosic wackes. However, their abundance is much less. Most wackes in the NCLB tend to be "clean", containing few lithic fragments other than chert, and also tend to be quartz rich throughout all wacke fields (>55 to 60% of framework is quartz).

The lithic fragments include medium-grained trondhjemitic clasts (common in wackes southeast of Casper Lake (local name)), serpentinized meta-ultramafic clasts, plagioclase or quartz phyric felsic metavolcanic rocks (some are >6 mm in size), chert clasts and chlorite-rich mafic clasts of probable metavolcanic origin. Small granule-sized quartz-fuchsite fragments compose up to 25% of the framework and are invariably poorly sorted and angular. Of note is the near absence of potassium feldspar grains in this type of wacke and any wacke from the area for that matter. Microcline was only observed in a single sample near Seeseep Lake, where it forms 5% of the rock.

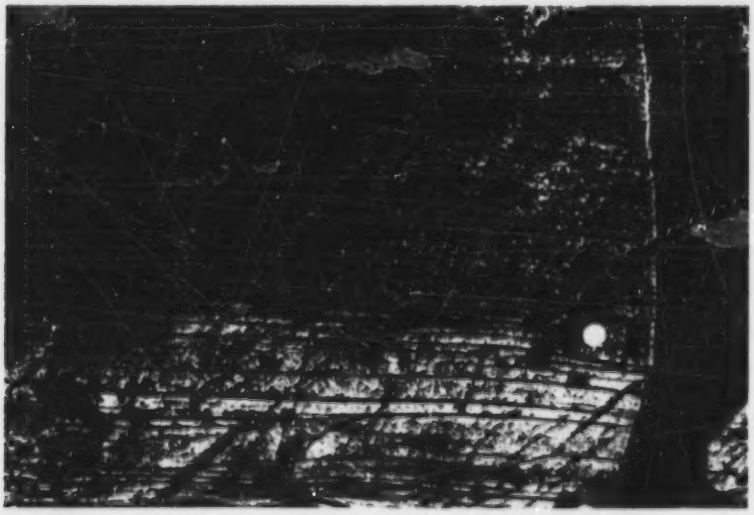


Photo 19. Thick, massive, arkosic wacke (top) overlies a finer grained, very thinly bedded wacke (bottom) at locality J30-34. Note the scour surface below the coin (2.3 cm diameter).

Mudstones

This unit includes slates, siltstones and phyllites that are spatially confined to the core of the ELS. These are best exposed along the north and south shores of Eyapamikama Lake from 90°50′W to 91°05′W. These rocks are black to light grey on weathered surfaces, and most are thinly coated with an organic rind, which obscures primary lamination. Light to dark brown interlaminations are common, and enable the delineation of primary features, such as ball and pillow structures, rip-up clasts, slumps and flame structures.

The small-scale lamination is defined by thin light to dark brown ribbon-like bands, from 1 to 10 mm thick, set against a black to light grey argillaceous matrix. The compositional differences of the contrasting laminations is not known, but may be related to grain size and to the abundance of nonphyllosilicate minerals giving a lighter colour to the rock in the browner laminae. Slates along the shores of Eyapamikama Lake are invariably characterized by a crenulation cleavage and pronounced penetrative lineation. The rock is most fissile along S_2 planes.

Important minerals include chlorite, biotite, quartz, plagioclase, sericite and muscovite. Chlorite-bearing slates and siltstones are confined to the southwestern part of Eyapamikama Lake, and give way to biotite-bearing slates as increased metamorphic conditions are reached to the north, west and east of Eyapamikama Lake.

Mudstones are commonly interstratified with 1 to 5 cm thick wacke, forming turbidite couplets. Interbedded mudstone–wacke has not been established as a mappable unit in the western Eyapamikama Lake map area, but is extensive in the eastern part of Eyapamikama Lake. A variety of rock types are grouped with these turbidite couplets, ranging from predominantly massive wacke with minor mudstone as a cap to an A–B–E type Bouma sequence through to a predominantly mudstone sequence with sparse 1 to 2 cm wacke interbeds.

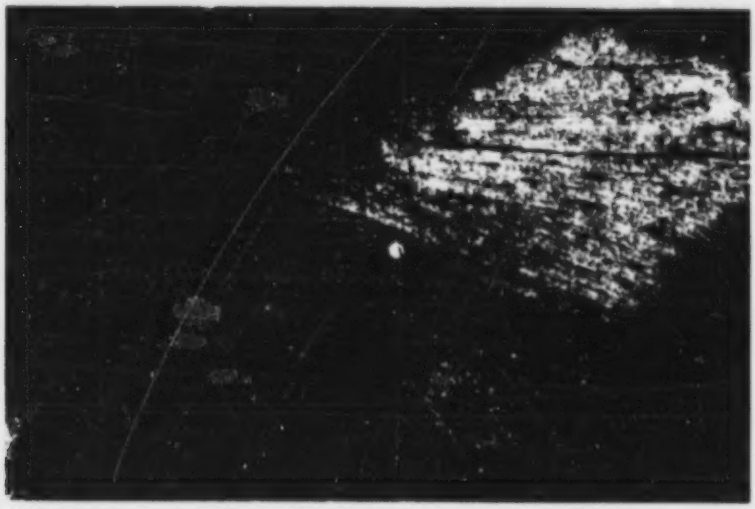


Photo 20. Large-scale, cross-trough stratified arkosic wackes in boulder exposed at low water level on the east side of an unnamed island, 1 km east of locality J30-19. Coin diameter is 2.3 cm.

East Eyapamikama–Opapimiskan Lakes Area

Southeast of Eyapamikama Lake, the ELS progressively tapers from 3 to 0.3 km and apparently changes into a mixed sedimentary sequence. This is composed of laminated to thinly bedded wackes, feldspathic arenites, biotite-chlorite metapelites, and amphibole-rich wackes with local intercalated felsic metavolcanic rocks throughout.

The amphibolite-rich metawackes, 0.5 to 2.5 cm in bedding thickness, exhibit a marked spatial restricted to contact zone with the NRV. With increasing distance from this contact, the percentage of mafic rocks decreases rapidly (1 to 2%), along with a concomitant increase in feldspathic arenite and wacke. The clastic constituent is similar to the lithologically diverse clastic sequences exposed south of Castor and Pollux lakes.

HEATON LAKE METASEDIMENTARY ROCKS

These rocks, which form part of the ELS, is a 40 km long continuous unit between Markop and Obabigan lakes (Figure 3). The Heaton Lake metasedimentary rocks are composed of 2 dominant types. The first type is quartz wackes and quartz arenites with minor amounts of felsic volcanic epiclastic metasedimentary material. The second type is made up of a variety of poorly sorted compositionally immature wackes, conglomerates and mudstones. The bulk of the Heaton metasedimentary rocks belong to the first category. On the southern shoreline of Heaton Lake, highly deformed, medium-grade quartz arenites and quartz wackes are well exposed. These 10 cm to metre thick, east-striking beds are sporadically interrelated with plagioclase-rich arkosic units up to several metres in thickness or with thin, centimetre-thick phyllite.

The quartz arenite and quartz wackes of the area are composed of up to 100% framework quartz or coarse, internally sutured, polycrystalline, detrital grains. Zircon and tourmaline are accessory minerals along with occasional sulphides and garnet. Although rounded zircons and garnets have been observed, it is not clear whether these grains have been abraded tectonically or during sedimentary transport.

Elsewhere, quartz arenites and quartz wackes have been observed just northeast of Wesley Lake, midway between Heaton and Neawagank lakes, north of Luras Lake and as a tectonic enclave in tonalite terrane at Obabigan Lake.

Quartz-rich intrusive rocks are interpreted to represent the dominant provenance for these metasedimentary units, however, some of the quartz wacke units that are closely associated with felsic metavolcanic rocks reveal embayed, unabraded framework quartz grains indicating a dominantly felsic hypabyssal or extrusive source rock. Quartz wackes, such as these, are typically of high matrix content, exceeding 50%, and are mixed with sericitized quartz-rich, volcaniclastic and fragmental rocks.

Metasedimentary rocks of the second type are exposed along the northeastern shore of Neawagank Lake, along the channel that joins with Obabigan Lake and on the southwestern shore of Obabigan Lake. These metasedimentary rocks are compositionally less mature, but still contain 60% quartz in mudstone units. No bedforms other than planar lamination and bedding were observed, probably due to the high strain state of most of these rocks. Minor mylonite zones transect these rocks and typically completely obliterate primary bedding. A deformed polymictic conglomerate unit on the southwest shore of Obabigan Lake contains quartzite and trondhjemite pebbles and exhibit stretching ratios of 10:1 and 20:1. Mafic, ultramafic and felsic metavolcanic clasts types are also abundant.

PIPESTONE RIVER AREA

Metasedimentary rocks of this area, south of Karl Lake and northwest of Markop Lake, consist of a heterolithic mélange of polymictic conglomerate and immature wackes. On the Pipestone River, conglomerate lies in sheared contact with spinifex-textured komatiitic metavolcanic rocks of the OLV. Facing data and the presence of fuchsite in quartz wackes of the Markop Lake area suggest that the metasedimentary rocks overlie these komatiites. Conglomerates are dominated by an aphanitic to coarse-grained quartz arenite to quartz wacke clast population, which commonly exceeds 50% of the rock (Photo 21). A quartz-rich, texturally immature subarkosic wacke to arenite matrix composes between 30 and 50% of this conglomerate. Sand-sized, angular quartz can constitute up to 85 to 90% of the matrix.

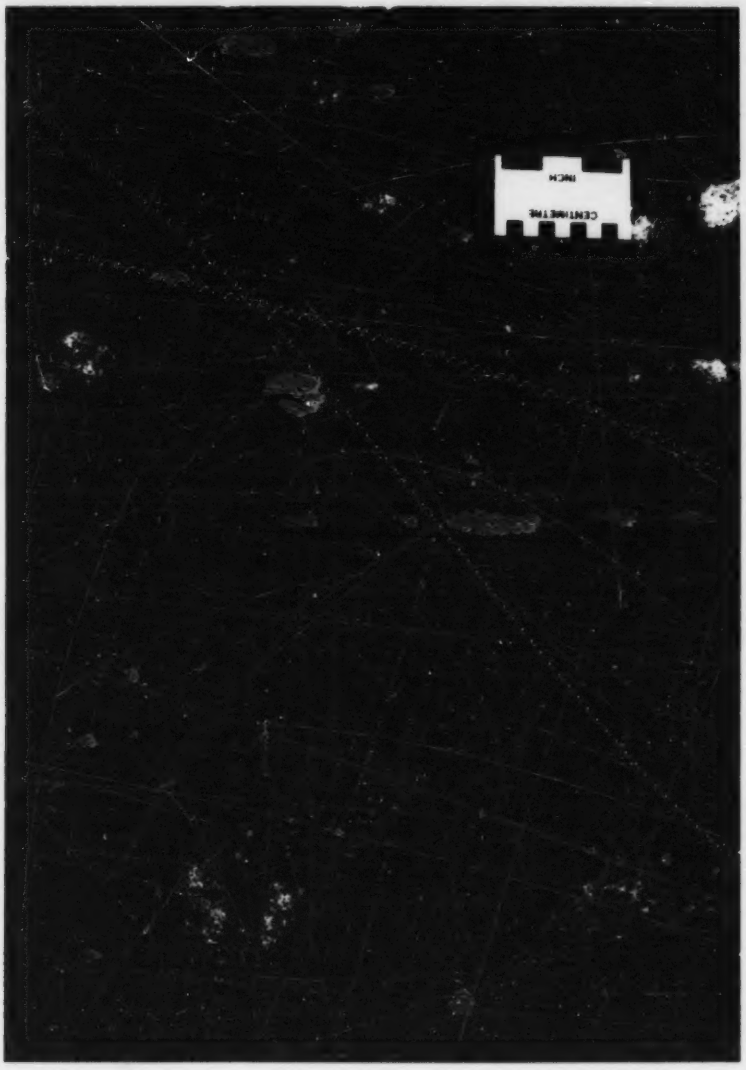


Photo 21. Clasts of quartz arenite, quartz wacke and angular meta-ultramafic rocks within clast-supported, pebble to cobble, polymictic conglomerate below the waterfalls on Pipestone River at locality BB25-14.

The presence of the numerous quartz arenite and quartz wacke clasts indicates that these coarse metasedimentary rocks were derived, in part, from reworking of an older quartz-rich sedimentary provenance. Quartz arenite interbeds occur within the conglomeratic sequence and, locally, may display cross-trough lamination (Photo 22).

Subordinate clast types include banded iron formation, felsic metavolcanic rocks, chert, vein quartz, quartz-fuchsite and foliated tonalite. These clasts suggest that the surrounding komatiitic metavolcanic rocks underlie the immature coarse clastic metasedimentary rocks and that such units possibly formed a stratigraphic sequence which included all these rock types. If this interpretation is correct, the underlying stratigraphy may be correlative with the quartz arenite, banded iron formation, and komatiite observed within the KLS and KLV of the western Eyapamikama Lake area.

BARRIGAR–LIBERT LAKES AREA

Metasedimentary rocks in this area are distributed along the narrow core of a northeast-striking limb of the NCLB. They form a thin band, less than 1 km thick, which extends along strike to a length of 20 km. Preservation of these rocks diminishes from north to south. The best exposures are located along the shores of the northwest arm of Barrigar Lake. In this area, the dominant rock type is biotite-muscovite-minor garnet-bearing, interbedded clastic metasedimentary unit. The protoliths to these rocks probably included thinly bedded mafic to felsic epiclastic metasedimentary rocks, bedded lithic wackes, siltstone–wacke couplets and interbeds of interlain tuffaceous rocks of ultramafic to felsic compositions.

Bedforms are rarely preserved in the area, with the exceptions of primary bedding and possible graded interbeds. The rocks were most likely to have been deposited in a distal environment through the action of turbidity currents along the flanks of slopes to volcanically active regions.

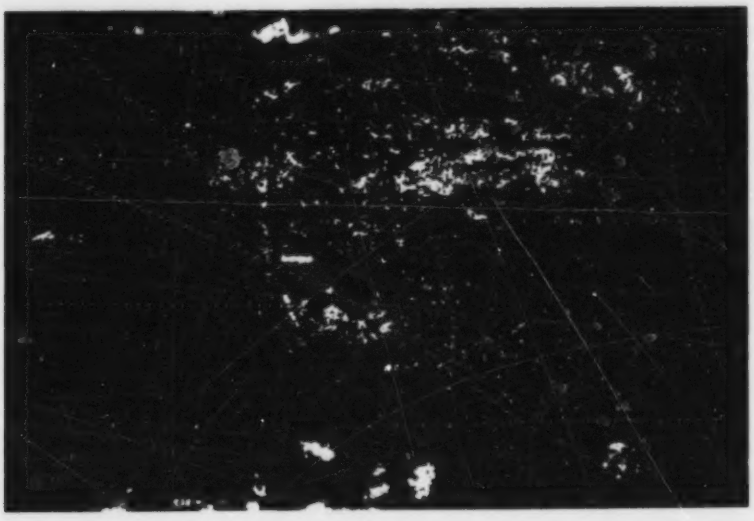


Photo 22. Cross trough lamination in quartz arenite associated with conglomerate. Sedimentary facing direction indicated by arrow. Photo taken at locality Z25-1 (same as Photo 29).

Only at 1 outcrop, west of Barrigar Lake, is there any indication of coarse metasedimentary units. There, a highly deformed tonalite boulder conglomerate is situated in a dominantly meta-ultramafic unit. Several of the boulders are internally foliated with no evidence of post-deposition strain imposed upon the spherical clasts. This is interesting in that it corroborates evidence for a predepositional phase of regional compression from the Eyapamikama Lake area. In the central Barrigar Lake area, it can be demonstrated that garnet-biotite-amphibolite-bearing metasedimentary rocks have been affected by 2 major deformations.

PROVENANCE STUDIES

The Quartz Problem

A notable feature of the metasedimentary rocks of the western Eyapamikama Lake, the Pipestone River and the Heaton Lake areas is the high quartz content. Detrital quartz concentration, within the metawackes of the Eyapamikama Lake metasedimentary sequence, generally exceeds 50% and commonly accounts for 75% of the rock (Figure 7). The lower part of the Keeyask Lake metasedimentary section is also quartz rich, with the quartz concentrations in both wackes and arenites ranging from 80 to 99%. The wacke matrix of conglomerates of the Pipestone River area attain quartz contents of over 90%.

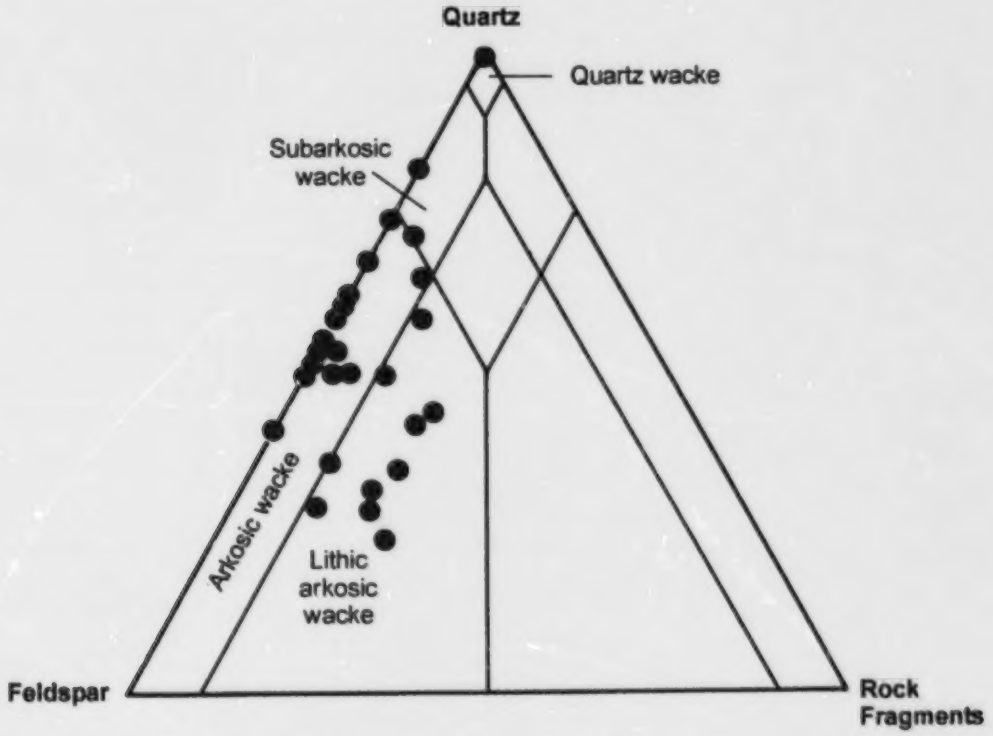


Figure 7. McBride plot (*after* McBride 1963) of point counts for metawackes from the Eyapamikama Lake assemblage. Each sample represents 300 counts from thin-section material.

The quartz framework of arenites from Heaton Lake can approach 100%. The derivation of metasedimentary rocks with such high quartz concentrations logically involved source rock(s) of initially elevated quartz contents. Furthermore, an efficient concentration mechanism must have been operative once the quartz grains were liberated from the source rocks. Concentration mechanisms can be quite varied and may act in combination. Prolonged exposure to intense weathering and long transport distances can result in compositionally mature quartz-rich sediments, provided that the source terrane contains a reasonable amount of free quartz of suitable grain size. For example, a dominantly mafic–ultramafic terrane could not produce a quartz arenite no matter how intense the weathering regime, simply because there are no quartz phenocrysts to work with. For source rocks which do contain quartz grains of sufficient size, however, prolonged periods of sorting and abrasive action can result in concentration of quartz, especially in a stable marine margin setting, such as a coastal beach or barred beach environment. There, tidal reworking and degradation of detritus leaves only the most stable grains intact, while fine mud-sized particles are selectively removed. The remaining quartz-rich sands become texturally mature from constant abrasion and also become enriched in resistant heavy minerals, such as zircon, tourmaline, apatite, rutile, beryl and topaz.

Source of Keeyask Lake Quartz Arenites

Compositionally and texturally mature sediments, such as the quartz arenites of the Keeyask Lake metasedimentary assemblage, are rare in Archean terranes of the Canadian Shield (Donaldson and Ojakangas 1977). Although quartz arenites have been located on every Archean craton in the world, they contribute only a minor percentage to the total volume of Archean rocks (Erikkson 1979). They are more abundant in some areas than others, but are extremely rare in areas of the Canadian Shield, such as the southern subprovinces of the Superior Province (Lowe 1982).

From petrographical evidence alone, it is difficult to discern the specific nature of the source terrane for the quartz arenites. For instance, a high-grade gneissic basement or a felsic metavolcanic terrane can produce quartz grains that appear quite similar after extensive abrasion. Source terranes can also be quite complicated, because Archean cratons are mosaics of complex overlapping terranes that include abundant mafic components. Some terranes show a higher probability as a source of quartz, while others are simply inadequate (Donaldson and Jackson 1965). In certain areas, for example, at North Spirit Lake in the northern region of the Superior Province (Wood 1977, 1980; Donaldson and Jackson 1965; Donaldson and Ojakangas 1977), volume calculations of quartz within quartz-rich wackes and quartzites revealed that 30% of the total sand fraction of this greenstone belt was sand-size quartz. This calculation places difficult volume expectations on sources such as hydrothermal vein systems as a predominant source for quartz arenites (although hydrothermal quartz may have provided a minor contribution to the quartz budget). As mentioned earlier, ultramafic and mafic terranes are not suitable as source rocks due to a lack of sand-sized phenocrysts. The only remaining protoliths, which are feasible sources of quartz, are coarse-grained plutonic rocks, porphyritic acid volcanic rocks and older sedimentary rocks. The upper limit of quartz in felsic plutonic rocks is about 45%, although little of this is sand sized. The quartz porphyry contains up to 10% quartz phenocrysts, but most are less than 1.0 mm, in comparison to the average framework grains of the quartz arenites, which usually are greater than 1.0 mm. For these rocks to act as a major primary source, intense chemical weathering would be necessary to produce a sand grain fraction containing >95% quartz. Previously formed quartz-rich sedimentary rocks, such as cherts or quartz-rich feldspathic arenites and wackes, also can act as a suitable source rock for the derivation of a quartz arenite.

It is generally concluded that quartz arenites, particularly those deposited via fluvial transport and tidal action, were formed by intense chemical weathering of a felsic protolith such as pre-existing quartz-

rich metasedimentary rocks, quartz porphyry or quartz-rich plutonic rocks (Schau 1977; Donaldson and Jackson 1965), coupled with prolonged transport and abrasion. Some quartzites do not show a high degree of sphericity and rounding of grains, but contain up to 99% quartz. In some cases, these quartzites contain abundant euhedral embayed quartz, indicative of a felsic hypabyssal or volcanic source rock. An example of felsic metavolcanic rocks as a source is provided by the Strelley Pool quartzites, Pilbara block, Western Australia (Barley et al. 1979). This type of quartz arenite meets the criteria for mineralogic maturity, but lacks the textural maturity needed to invoke lengthy erosion and transport for its mode or origin. Thus, to characterize properly the nature of the source terrane, all features of the rock must be examined, including primary structures, quartz content, sphericity and roundness of grains, and the type of grains, that is, embayed, euhedral, strained, inclusions within grains, authigenic overgrowths and degree of recrystallization.

Several petrological features of quartz arenites in the Keeyask Lake metasedimentary assemblage place constraints on the nature of the source rock. Euhedral zircons, which comprise less than 5% of the detrital mineral population, imply an igneous source. The zircon population is quite similar to that of the stratigraphically underlying Agutua Arm felsic metavolcanic rocks.

Felsic plutonic clasts have not been observed in any of the coarse-grained interbeds of quartz pebble conglomerates of the KLS. Plagioclase-quartz aggregate grains have also not been observed. These observations imply that tonalite-trondhjemite-granodiorite did not constitute an important protolith for the quartz arenite, unless these rocks were totally eliminated by chemical weathering. The 10 m thick regolith, which underlies the quartz arenite, may signify this as a period of intense chemical weathering. The lack of strained quartz grains and metamorphic minerals, such as garnet or kyanite in the quartz arenite, suggests that the source rock was not an older metamorphic complex. Furthermore, the presence of sporadic beryl and topaz may be a consequence of peraluminous granitic rocks in the provenance.

Thus, the field and petrographic evidence is consistent with the dominant source rock being one of a combination of the following rock types:

1. quartz-phyric felsic metavolcanic rocks,
2. quartz-rich hypabyssal rocks, and
3. quartz diorite, tonalite and trondhjemite.

The most plausible candidate is felsic metavolcanic rocks of the Agutua Arm assemblage.

Source of Quartz-Rich Metasedimentary Rocks of the Eyapamikama Lake Assemblage

The Eyapamikama Lake metasedimentary assemblage represents a different sedimentary environment than that of the Keeyask Lake metasedimentary assemblage. The ELS consist of distinctly different lithologic units with sedimentary bedforms in contrast to those of the KLS (deKemp 1987). The entire Eyapamikama Lake section is much thicker, probably by 2 orders of magnitude or more. The volume of sediment, thus, would necessarily be higher by this same order of magnitude if deposited over an equivalent area. However, the Keeyask Lake metasedimentary rocks may have initially contained regionally extensive quartz arenites, which were reduced to a local quartz arenite by erosion.

The Eyapamikama Lake metasedimentary rocks possibly formed in an entirely different tectonic regime than were the underlying successions. They were initially deposited in an active volcanic environment that was surrounded by a rapidly rising granitoid terrane, as is evident from the intercalation of ultramafic flows with conglomerates, which contain a significant tonalite clast fraction. This setting

contrasts with the tectonically stable platformal environment that prevailed during deposition of the Keeyask Lake stromatolite-bearing quartz arenites.

Quartz- and plagioclase-rich metasedimentary rocks of the ELS are texturally immature and commonly occur in massive, thick interbeds, which implies that deposition was rapid throughout the area. Subsequent to the initial pulse of coarse sedimentation, volcanic activity appears to have ceased.

The quartz and plagioclase-rich Eyapamikama Lake metawackes may have been derived almost exclusively from uplifted surrounding granitoid terrane, but some detritus was probably added from reworked upper Agutua Arm felsic metavolcanic rocks and from uplifted segments of the Keeyask Lake quartz-arenites. Unroofed felsic intrusions and adjacent felsic volcanic centres probably provided the bulk of this detritus. In some areas, such as eastern Eyapamikama Lake, felsic volcanic centres may have been active during the initial stages of deposition, whereas, at the other areas, such as western Eyapamikama Lake, coarse sedimentation was concomitant with ultramafic volcanism.

The high modal quartz and plagioclase of the Eyapamikama Lake metasedimentary rocks, and the angularity and poor sorting of framework grains, support the rapid deposition of an immature sediment adjacent to quartz-rich highland provenance, as possibly represented by the Weagamow batholith or Schade Lake gneissic complex.

Lithic arkosic and lithic subarkosic metawackes imply local contamination by detritus from mafic and felsic volcanic centres. In the Seeseep Lake area, this contamination is almost entirely from a felsic metavolcanic source, whereas, in the Keeyask Lake area, the lithic arkosic wackes indicate a mafic volcanic input. The arkosic wackes in the northwestern Eyapamikama Lake region, southeast of Casper Lake (local name), contain only plagioclase and quartz. These wackes are texturally immature and form massive beds up to several metres thick. They commonly contain trondhjemite and tonalite granules which may reflect derivation from the unroofing of the Weagamow batholith to the southwest during regional uplift.

Megascopic Modal Analysis

Megascopic modal analysis conducted on the basal conglomerates of the Eyapamikama Lake metasedimentary assemblage aid in the interpretation of provenance (Tables 2 and 3). These analyses establish a variation in clast populations throughout the area and, therefore, suggest that 3 source terranes

Table 2. Summary of clast populations (in percent of total clast volume).

Station No. (Points counted including matrix*)	**J30.08** (1000)	**J30.42** (200)	**J30.43** (100)	**1-17-13** (100)	**J27.06** (600)	**Total Means** (2000)
Felsic intrusive rocks	55	51	48		2	35
Mafic intrusive rocks	14	10	24	5	8	12
Mafic–ultramafic volcanic rocks	17	21	14	26	82	37
Felsic volcanic rocks	5	12	8	63	7	9
Hydrothermal products**	6	1				3
Chemical sedimentary rocks	3	1		5	1	2
Clastic sedimentary rocks		3	6			1
Total	100	99	100	99	100	99

**See* Table 3 for matrix content

***Hydrothermal products: vein quartz, quartz fuchsite and quartz ankerite

were involved in evolution of the coarse conglomerates. The dominant clast-bearing units are

1. trondhjemite conglomerates
2. felsic metavolcanic conglomerates, and
3. ultramafic–mafic metavolcanic conglomerates

The trondhjemite-clast conglomerates (localities J30-8, J30-42 and J30-43) contain nearly 50 volume % felsic intrusive clasts (mainly trondhjemite and subordinate tonalite and granodiorite). These felsic intrusive rocks are preserved as well-rounded, cobble to boulder clasts, which indicate extensive mechanical abrasion. Similar felsic-rich cobble to boulder conglomerates occur within the North Spirit Lake belt to the southwest (Wood 1977), which reveals a regional significance of this clast type within

Table 3. Megascopic modal counts of basal conglomerates.

Station No. (Points counted including matrix*)	**J30.08** (1000)	**J30.42** (200)	**J30.43** (100)	**1-17-13** (100)	**J27.06** (600)	**Total Means** (2000)
Granodiorite	2.0	7.5	3.0			1.9
Tonalite	4.2	9.5	5.0			3.3
Trondhjemite	11.4	16.0	16.0		1.5	8.5
Subtotal						13.7
Felsic volcanic rocks	0.4	4.0	2.0	12.0	0.7	1.5
Quartz porphyry	0.6	3.5	1.0			0.7
Quartz sericite schist	0.3	0.5	1.0			0.3
Hornblende phyric	0.2	0.5				0.2
Subtotal						2.7
Quartz fuchsite	1.1	0.5				0.6
Vein quartz	0.6					0.3
Quartz ankerite	0.1					0.1
Subtotal						1.0
Diorite	4.3	6.5	12.0		2.5	4.2
Gabbro	0.1			1.0	3.5	1.1
Ultramafic intrusive rocks					0.3	0.1
Subtotal						5.4
Intermediate volcanic rocks	0.1				4.8	1.5
Mafic volcanic rocks:						
Unsubdivided	4.9	13.0	6.0	4.0	60.3	22.3
Variolitic					3.2	1.0
Ultramafic rocks:						
Volcanic rocks (komatiite)	0.7	0.5	1.0	1.09	1.7	1.0
Subtotal						24.3
Banded iron formation	0.6	0.5			0.5	0.5
Chert	0.5			1.0	0.5	0.5
Quartz arenite	0.1					0.1
Possible sediment (reworked felsic tuff?)		2.0	3.0			0.3
Matrix	67.8	35.5	50.0	81.0	20.5	50.0
Totals	100.0	100.0	100.0	100.0	100.0	100.0
(Pre-deformed clasts)	0.4	15.0	11.0	?	2.2	6.6

this portion of the Sachigo Subprovince. Many of the felsic intrusive clast conglomerates of the Eyapamikama Lake assemblage bear a petrographic similarity to granitoid rocks of the surrounding batholiths. Such clast types increase in angularity and size with increasing proximity to the Weagamow batholith to the west. This infers, at least, that some of the tonalite-trondhjemite-granodiorite batholiths, which bound the North Caribou Lake greenstone belt, provided a source for these clasts.

Trondhjemite-tonalite-granodiorite batholiths exhibit a pre-D_2 intrusive relationship with adjacent supracrustal rocks of the North Caribou Lake belt and, thus, may have acted as a source for granitic cobbles and boulders in the overlying sedimentary rocks. Thus, as the exposed KLS–ELS greenstone–metasedimentary contact reveals little or no time break between the end of mafic volcanism and the onset of clastic sedimentation, it follows that emplacement of the surrounding batholiths commenced during active mafic and ultramafic volcanism.

Importantly, all 3 clast population types exhibit a significant number of mafic and ultramafic clasts. However, these rocks may have originated from proximal sources. Within the trondhjemite-dominant conglomerates, there are at least 10% quartz porphyry or quartz-phyric felsic volcanic rocks (Photo 23). Clasts of quartz fuchsite, clear and milky vein quartz, quartz ankerite and carbonate-chlorite occur in this population as well. These trondhjemite-clast conglomerates also contains the highest percentage of foliated clast types, most of which are diorite-gabbro and trondhjemite.

Felsic metavolcanic-dominant conglomerates, the second most common type, represents proximal to medial deposits adjacent to active felsic volcanic centres. These volcanic centres may have been completely removed during the tectonically unstable period before and during formation of the Eyapamikama Lake conglomerates. Alternatively, the felsic volcanic clasts may have originated from uplifted Agutua Arm terrane, which contains rock types identical to those in the conglomerates. The best example of this conglomerate type occurs near Seeseep Channel (locality J44-12), in Seeseep Lake, where about 90% of the conglomerate clast population comprises angular felsic pumice and lapilli fragments supported by a matrix of felsic ash. A small island in the southwestern part of Eyapamikama Lake, exposed only at low water levels, mainly contains felsic volcanic fragments (more than 60% of total clast population). Many of these clasts are angular and distributed along bedding.

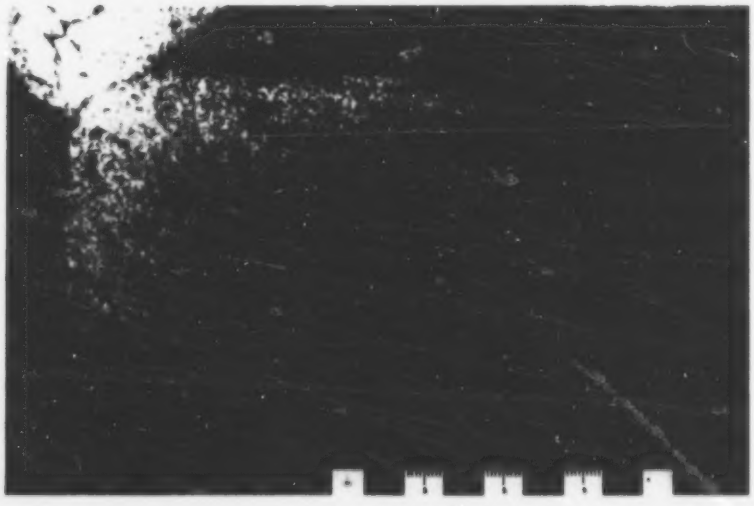


Photo 23. Rounded clast of quartz phyric felsic metavolcanic rock in basal conglomerate of the Eyapamikama Lake metasedimentary assemblage at locality J30-16.

Ultramafic- and mafic metavolcanic-dominant conglomerates (Photo 24) may have originated from the underlying Keeyask Lake metavolcanic rocks. Felsic intrusive and felsic metavolcanic rocks comprise less than 10% of the clast population. The clast population from ultramafic–mafic metavolcanic conglomerates are composed of clast-supported, angular, mafic and ultramafic blocks (Photo 18). These conglomerates are inferred as alluvial and talus debris, which accumulated at the base of a steep scarp. The matrix of the conglomerate is a quartz-rich wacke, which probably filled cracks between angular metavolcanic blocks during burial of the coarse talus deposit by a separate fan lobe. All rock types of the Keeyask Lake metavolcanic section are incorporated into this conglomerate: coarse variolitic mafic metavolcanic rocks, clasts of mafic flow breccias, spinifex boulders and pillow-selvage debris.

Deposition was concomitant with the later stages of Keeyask Lake ultramafic volcanism, because the conglomerate deposit contains spinifex-textured ultramafic flows up to 2 m thick. Mafic and ultramafic blocks within this conglomerate commonly form a jigsaw-like pattern, which indicates *in situ* fragmentation after consolidation (Photo 18).

A common feature of all 3 conglomerate types is the content of exotic clast, which include banded iron formation, chert and quartz arenite (Photo 17). These clasts are distributed throughout all conglomerates, but collectively comprise less than 1% by volume of the conglomeratic deposits. These clast types most likely originated from the older Keeyask Lake metasedimentary rocks Thin sections of quartz arenite pebbles and banded iron formation boulders reveal similar textural and mineralogical characteristics to the *in situ* rocks from which they were most plausibly derived. This observation provides additional evidence that the western Eyapamikama Lake metasedimentary cycle is underlain by products of 2 distinct sedimentary cycles.

To summarize, most of the basal conglomerates of the Eyapamikama Lake metasedimentary sequence can be interpreted as proximal submarine fan conglomerates, mainly derived from a felsic intrusive (trondhjemite-tonalite-diorite) provenance augmented by mafic–ultramafic volcanic and felsic volcanic rocks. This mixing may have been the result of clastic debris from sialic-dominated highlands transported via contrasting submarine fan truncation and overlap (Lowe 1982) into existing mafic volcanic grabens. Such overlap would be a common feature along the leading edges of detrital aprons which surround the active felsic volcanic centres.

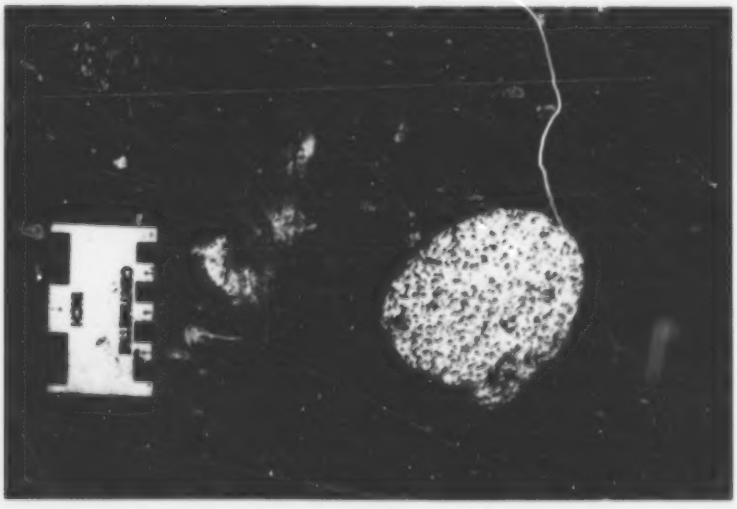


Photo 24. Well-rounded tonalite and angular felsic metavolcanic clasts within a dominantly ultramafic to mafic metavolcanic conglomerate situated at the base of the Eyapamikama Lake metasedimentary assemblage at locality J27-6.

INTRUSIVE ROCKS

Metamorphosed Intrusive Rocks

MAFIC AND ULTRAMAFIC INTRUSIVE ROCKS

These rocks, although scattered throughout the map area, are mainly concentrated in the Agutua Arm area and between the Pipestone River (at Karl Lake) to Neawagank Lake. Mafic and ultramafic metaplutonic rocks are typically associated with mafic metavolcanic units. Exceptions include the Karl Lake intrusive complex and rare metagabbro dikes in the ELS (Satterly 1941; Breaks, Osmani and deKemp 1986, 1987a). The intrusive masses include individual dikes, lenticular masses and irregularly shaped plutons. Metamorphosed rock types include gabbro, diorite, pyroxenite, peridotite and quartz gabbro, in approximate order of decreasing abundance.

Agutua Arm Area

Small pods and lenses of mafic and ultramafic rocks are common in the AAV. Compositional variants include gabbro, pyroxenite, peridotite and possible dunite. Many of the individual masses are highly tectonized and altered, such as the talc-serpentine rock exposed on an island midway along Agutua Arm, south of the channel between Agutua Arm and Weagamow Lake. However, in view of a distinct absence of komatiitic metavolcanic rocks and lack of exposed contacts in the AAV, such meta-ultramafic rocks are most likely intrusive. A significant, northwest-striking, linear aeromagnetic anomaly probably represents a continuation of Agutua Arm meta-ultramafic rocks, based upon the occurrence of metadunite at the village of Round Lake (Satterly 1941).

Several small lenticular gabbro-leucogabbro masses are located along the North Caribou Lake fault between Agutua Arm and the North Caribou River. These rocks are massive to locally sheared depending upon proximity to the fault zone, medium to coarse grained and, locally, form intrusive breccias with host mafic metavolcanic rocks.

Southeastern Part of the North Caribou Lake Belt

Mafic and ultramafic rocks commonly intrude the mafic metavolcanic units of the Opapimiskan Lake and Forester Lake assemblages and also occur within a tectonized high-grade terrane composed of tonalite gneiss and migmatized clastic metasedimentary rocks located 1.5 km north of the ELS at Karl Lake.

Metagabbro masses are present at Markop Lake, near Neawagank Lake, and just west of the Pipestone River. These rocks are massive, medium to coarse grained, porphyroblastic and consist essentially of hornblende and plagioclase. Little compositional variation is generally exhibited exclusive of crude layer segregation exhibiting plagioclase enrichment. Near Neawagank Lake, these rocks show gradation into quartz gabbro characterized by 5 to 10% blue quartz. These rocks are massive to locally sheared depending upon proximity to the fault zone, medium to coarse grained and, locally, form intrusive breccias with host mafic metavolcanic rocks.

Metaperidotite dikes are most common in the Forester Lake area and were first described by Boleantu (1961). These massive, red-brown weathering, medium- to coarse-grained rocks are up to 60 in width, as observed near the west end of Forester Lake (locality FF30-1). Possibly related, but highly tectonized, ultramafic rocks occur in several localities within amphibolitic mafic metavolcanic rocks of the Boyce Lake area (localities A103-2 and HH34-10).

A previously undocumented, small (15 by 70 m) ultramafic mass occurs 2 km northwest of Forester Lake. Although essentially converted to serpentine and talc, this mass displays conspicuous nodules (Photo 25). These vary from 2 to 40 mm in diameter and compose between 55 and 95% of the rock. Most of the nodule consists of secondary minerals, however, the outermost periphery contains olivine. Cumulate layering is evident. Nodule-free layers are commonly intercalated with those in which there is a gradual increase in nodule size normal to the layering.

Karl Lake Intrusive Complex

This 3 km^2, previously undocumented, moderately magnetic, metamorphosed, mafic–ultramafic intrusive mass is situated over the western end of Karl Lake, where it has intruded tonalitic gneisses and a small remnant of high-grade clastic metasedimentary rocks. The main rock types of this intrusion are pyroxenite, gabbro, and amphibolite (Photos 26 and 27). Anorthositic gabbro and anorthosite are considerably less common (Photo 28). Preserved magmatic layering (Photo 29) occurs in 1 locality on the Pipestone River (second set of rapids north from Karl Lake). Amphibolite, which is fine grained and similar in mineral composition to the gabbro unit of the intrusion, occurs along the Pipestone River just west of Karl Lake, and may actually represent a more intensely recrystallized variant of the metagabbro.

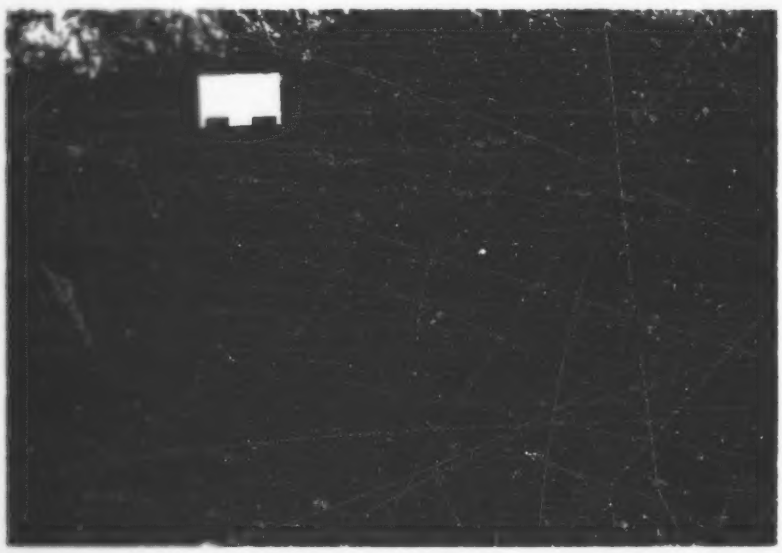


Photo 25. Nodular, olivine-bearing meta-ultramafic intrusive rock at locality EE28-7.

INTERMEDIATE AND FELSIC INTRUSIVE ROCKS

Intermediate and felsic plutonic rocks bound the North Caribou Lake belt in 3 distinct granitic batholithic complexes, namely the North Caribou Lake and Weagamow batholiths and the Schade Lake intrusive complex. Comparatively less is known of the granitoid rocks bounding the southern greenstone belt contact between Libert and Neawagank lakes. As emphasis on this survey was directed toward supracrustal rocks of the North Caribou Lake belt, only a cursory examination of the outer 0.5 to 1 km portion of the main intrusive bodies adjoining the belt was undertaken.

North Caribou Lake Batholith

This large batholith marks the southern, southwestern and western limits of the North Caribou Lake belt for a distance of 90 km between Randall and Libert lakes. It is possible that diapiric emplacement, at 2869±3.6 Ma (deKemp 1987), of this tonalite-trondhjemite-granodiorite complex was responsible for the pronounced flexure of the supracrustal contact.

Granitic rocks of this batholith are typically massive, medium grained, equigranular, and hypidiomorphic-granular. Adjacent to the contact, however, as noted at the western end of Seeseep Lake, the North Caribou Lake batholith consists of moderately foliated, recrystallized biotite trondhjemite and granodiorite with enclaves of amphibolitic mafic metavolcanic rocks. Typical samples contain 30 to 35% quartz, 55% plagioclase, and 5 to 10% biotite. The remainder consists of a variety of accessory minerals: epidote, titanite, opaque iron oxide, allanite and apatite. Plagioclase is euhedral to subhedral, commonly moderately altered to fine-grained epidote and/or sericite and, in rare cases, replaced by 5 to 10% potassium feldspar. Oscillatory zoning is discernible in a few large, relatively unaltered plagioclase grains. Quartz is anhedral and generally only incipiently recrystallized.

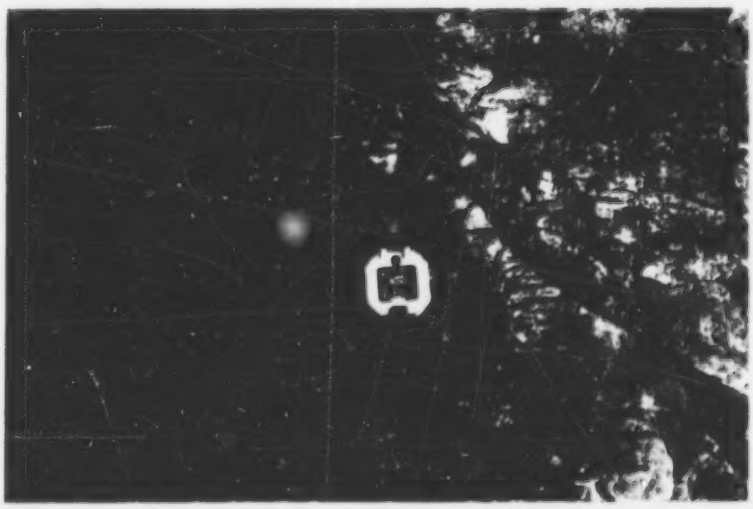


Photo 26. Well-developed box-work joint pattern, accentuated by weathering, within metapyroxenite of the Karl Lake intrusive complex at locality Z26-4.

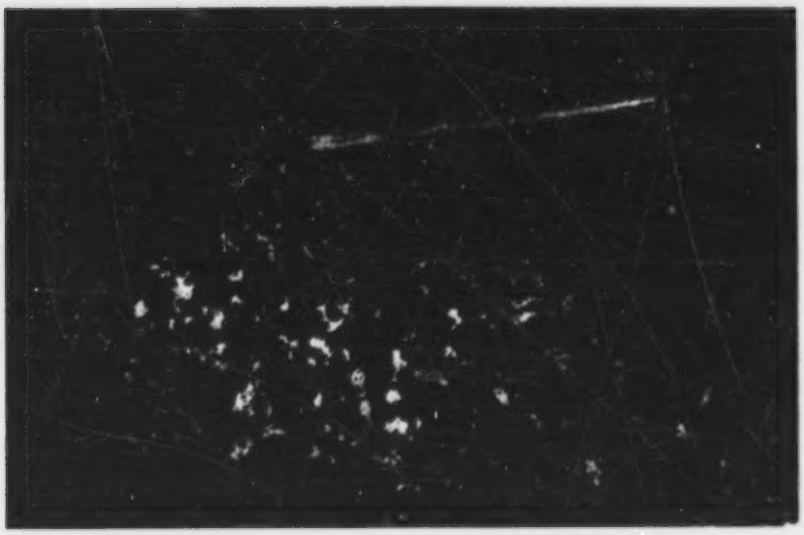


Photo 27. Metagabbro from the western part of the Karl Lake intrusive complex at locality Z25-1.

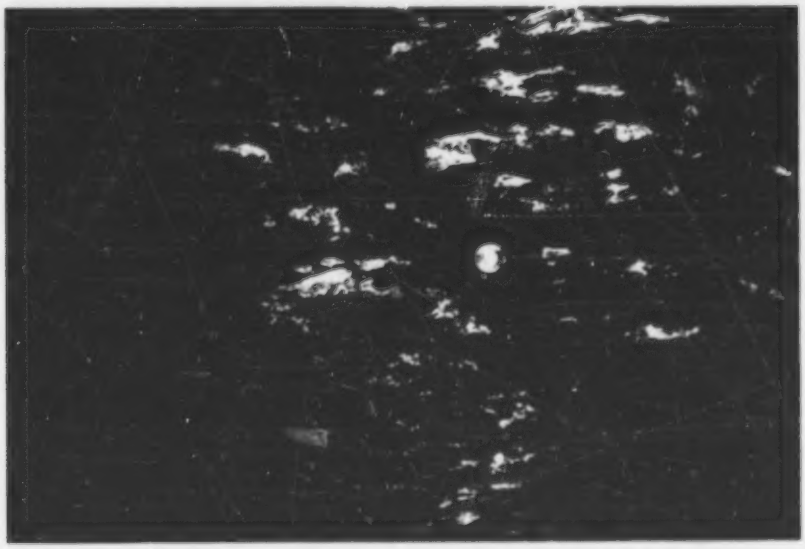


Photo 28. Coarse, highly deformed anorthositic gabbro from the Karl Lake intrusive complex at locality Z26-6. Coin diameter is 2.1 cm.

Weagamow Batholith

This elliptical granitic mass, emplaced at 2990±1.8 Ma (deKemp 1987) (Photo 30), is about 100 km^2 and forms the arcuate western and northwestern contact of the North Caribou Lake belt. The rocks are massive, medium grained, mainly hypidiomorphic-granular and predominantly trondhjemite (Figure 8).

Plagioclase composes 46 to 57% of the rocks from the batholith. It commonly occurs as euhedral to subhedral laths, some with well-developed oscillatory zoning, which are moderately to strongly saussuritized.

Quartz occurs as incipiently recrystallized grains occupying elliptical areas up to 7 by 9 mm, interstitial to plagioclase. Quartz content varies from 29 to 34% in most rocks, and up to 40% in a few. Potassium feldspar grains, less than 1 mm in diameter, occupy less than 9% of the rocks, and are mainly interstitial to plagioclase. Biotite occurs up to 9%, and commonly occurs in clot-like aggregates up to 4 mm across. Minor epidote, muscovite and calcite are commonly associated with the biotite clots, and represent possible deuteric alteration products. Accessory minerals are hornblende, tourmaline, chlorite, apatite, zircon, opaque iron oxide, allanite, titanite and pyrite. Sericite and clinozoisite are common alteration minerals.

Schade Lake Gneissic Complex

This map unit is located immediately north, northeast and east of the North Caribou Lake belt between Atikomik and Karl lakes. The complex is a highly deformed, recrystallized, commonly interbanded mélange composed of hornblende-biotite tonalite, biotite trondhjemite, biotite granite, biotite-hornblende quartz diorite and scattered amphibolite enclaves. A strong protomylonitic, ductile cataclastic zone is coincident with most of the metavolcanic–granitoid contact. This deformation zone is conspicuous topographically due to a prominent scarp with local relief up to 30 m.

Photo 29. Metagabbro layer, marked by compass, exhibits a possible, gravitational loading structure on gabbroic anorthosite at locality Z25-1.

Photo 30. Tonalite, at locality H23-1, from the western margin of the Weagamow batholith. A sample from this site provided a U/Pb zircon age determination of 2990 Ma.

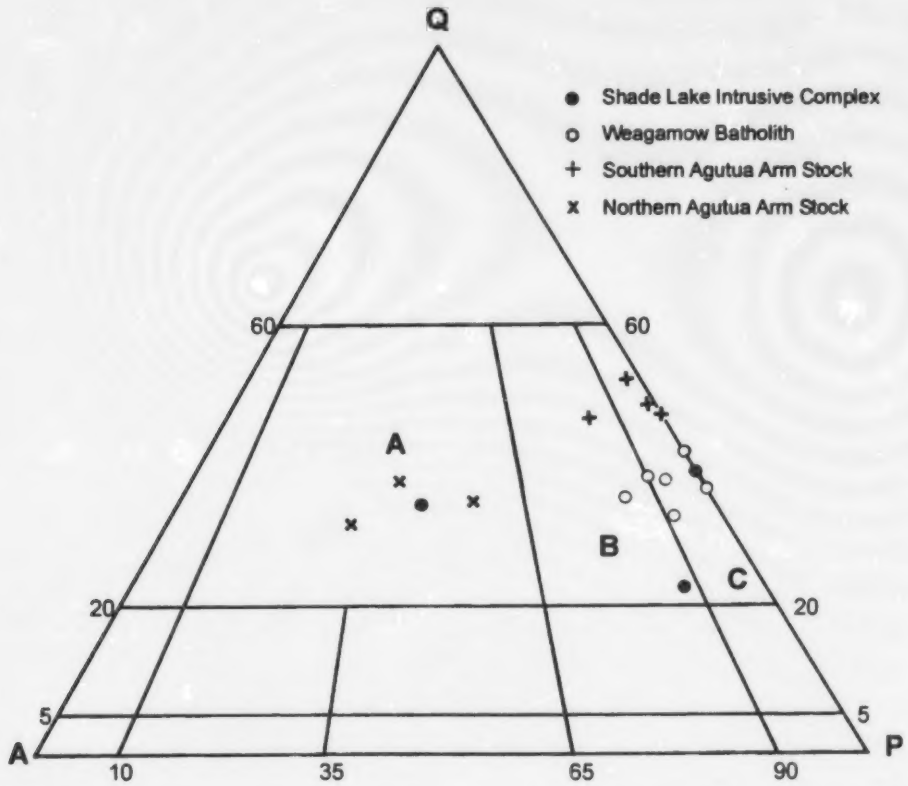


Figure 8. Modal variation of quartz, potassium feldspar and plagioclase for felsic and intermediate intrusive rocks.

These granitic rocks are more varied compositionally (Figure 8) and texturally than the previously described batholiths. A typical mylonitic tonalite is strongly foliated and lineated, and light grey on clean weathered surface. Quartz (25%) occurs mainly within thin, anastomosing fluxion bands up to 30 by 1 mm. Plagioclase comprises 60% polycrystalline aggregates, with individual grains commonly 0.2 mm in diameter.

Augen of plagioclase are also present and range from 1 by 1mm to 3 by 7 mm. Microcline (5%), is anhedral, typically 0.2 mm in diameter, and occurs in equant to augen shapes. Biotite (10%) is mainly distributed in thin trains defining a lineation and is subhedral to anhedral with a maximum size of 0.25 by 0.9 mm. Accessory quantities of muscovite, chlorite, epidote and titanite are mainly associated with the biotite-rich trains. Euhedral apatite is sparsely distributed.

Peraluminous Granitoid Rocks

These late D_2 rocks only locally intrude supracrustal units of the North Caribou Lake belt. However, with their apparent association with gold mineralization at Opapimiskan Lake (Breaks, Bartlett and deKemp 1985; Breaks et al. 1986; Breaks, Osmani and deKemp 1986), these distinctive granitoids may have played a role in the genesis of such mineralization. Petrographically, this group ranges from medium-grained to pegmatitic muscovite and biotite-muscovite trondhjemite, granite, pegmatitic granodiorite (Figure 8). Minor quartz monzonite and leucocratic quartz diorite may also be present. Notable accessory minerals are fluorite, tourmaline and green muscovite. Localities documented by this study include Eyapamikama Lake (localities H24-2, H24-4, I24-2,), Opapimiskan Lake (locality OP153-1), near Libert Lake (locality LW4-38), 1 km north of Graf Lake (OP127-8), and near the western end of Forester Lake (FF30-5) In most cases, these rocks are closely associated with clastic metasedimentary units.

Unmetamorphosed Mafic Intrusive Rocks

The youngest intrusive event is represented by diabase dikes of possible Proterozoic age. These dikes, which vary from 1 to 60 m in width, mainly strike north to northwest and, hence, may be related to the Pickle Crow diabase dike swarm (Sage and Breaks 1982).

Olivine lamprophyre was intersected in diamond drill holes during drilling conducted by Placer Dome Exploration and are apparently controlled by D_4 fault zones (Hall and Rigg 1986).

Metamorphism

Two patterns of regional metamorphism are discernible in supracrustal assemblages of the North Caribou Lake belt (NCLB). The first pattern shows that an overall increase in grade occurs between the northwest to southeast portions of the greenstone belt (Figure 9). Low-grade rocks with chlorite and/or biotite dominate the western part of the NCLB, which coincides with much of the AAV and ELS. In the mid-point of the belt beyond Doubtful Lake, metamorphism increases to medium grade and is marked by index minerals garnet, staurolite, cordierite, grünerite and, more rarely, sillimanite. This general increase in grade may relate to higher heat flow during regional metamorphism or represents an exposure of a deeper crustal level in the southeastern portion of the NCLB.

The second, and subordinate, regional metamorphic zonal pattern is evident only in the Eyapamikama Lake area and is marked by an increase from low to medium grade toward the north

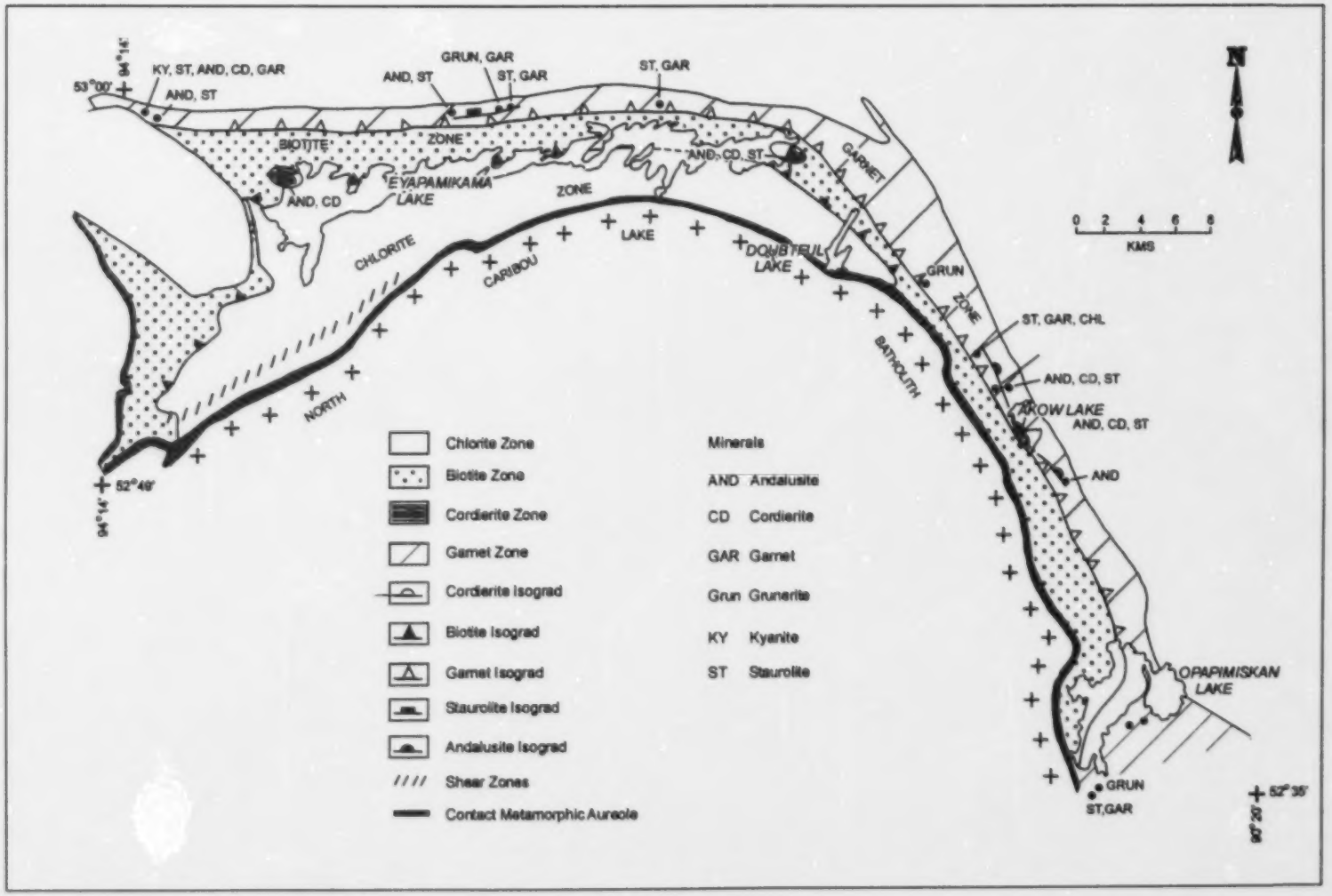


Figure 9. Metamorphic zones and isograds in the western part of the North Caribou Lake belt.

(Figure 9). Regional isograds here exhibit a pronounced convexity from north to northeast and lie parallel to strike of the greenstone belt. It is plausible that the diapiric emplacement of North Caribou Lake batholith induced this curvature in a pre-existing regional metamorphic isograded pattern. Evidence for this is revealed by a narrow amphibolitic contact aureole overprinted upon the regional chlorite zone. In addition, if this batholith represented the major thermal source responsible for producing regional isograds, a relationship opposite to that observed would be expected, that is, highest metamorphic grades adjacent to the batholith and progressively decreasing with greater distances from the contact. These relationships suggest an important relationship, namely that pre-Kenoran regional metamorphism in this part of the Sachigo Subprovince occurred prior to the emplacement of the North Caribou Lake batholith at 2870 Ma.

REGIONAL METAMORPHIC ZONES

Mineral assemblages and petrographic details of the various metamorphic zones are given in Breaks and Bartlett (1991) and Breaks et al. (1991). The observed sequence of low- to medium-prograde metamorphic zones, listed in Table 4, is very similar to those in other supracrustal belts of the Superior Province of Ontario (Pirie and Mackasey 1978; Thurston and Breaks 1978; Breaks 1989). Such zones were engendered under pressure–temperature conditions of low-pressure intermediate-type metamorphism (Miyashiro 1961), corresponding to Bathozone 3 of Carmichael (1978).

A unique feature of this metamorphic pattern is involvement of all aluminosilicate polymorphs, although kyanite is restricted to 2 occurrences. Regional distribution of grünerite within medium-grade banded iron formation is another distinct metamorphic feature. Replacement of magnetite by grünerite occurs in banded iron formations hosted by the NRV, LLV, OLV, and FLV. Grünerite apparently accompanies all known banded iron formation hosted gold mineralization in the NCLB.

Metamorphic Conditions

Metamorphic conditions are best estimated from assemblage data of the staurolite-bearing, medium-grade zones. The interpreted path of metamorphism (Figure 10) suggests a temperature range of 400 to 500°C at load pressures of 3 kilobars or less.

Critical reaction curves used to constrain these conditions within the andalusite field include the staurolite-in isograd of Froese and Gasparinni (1975):

$$\text{chlorite} + \text{almandine} + \text{muscovite} = \text{staurolite} + \text{biotite} + \text{quartz} + H_2O$$

and the staurolite disappearance reaction of Hoschek (1969):

$$\text{staurolite} + \text{muscovite} + \text{quartz} = Al_2SiO_5 + \text{biotite} + H_2O$$

Estimated *P–T* conditions in the staurolite-andalusite-cordierite zone compare favourably with the garnet-biotite and arsenopyrite-iron sulphide geothermometry investigations of Hall and Rigg (1986, p.132). These workers estimated a temperature range of 500 to 550°C at a pressure of 3 kilobars for medium-grade metapelites from the Opapimiskan Lake area.

Table 4. Metamorphic zones of the North Caribou Lake belt.

Metamorphic Grade	Zone
Low	Chlorite
	Biotite-chlorite
Medium	Garnet-biotite
	Staurolite-chlorite-garnet
	Staurolite-cordierite-andalusite
	Staurolite-kyanite
	Cordierite-andalusite

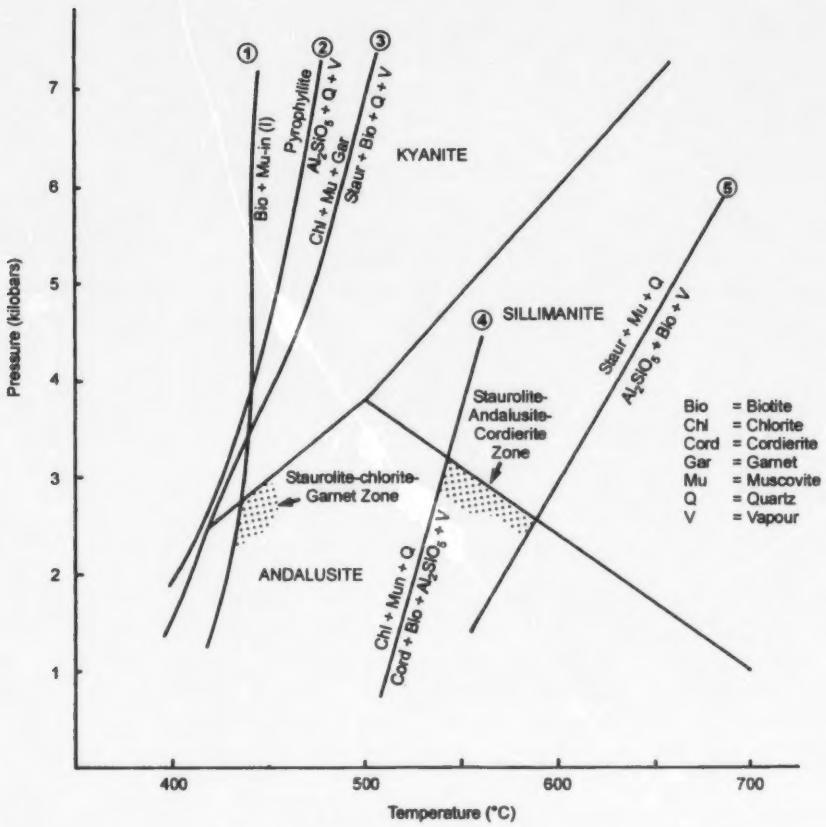


Figure 10. Metamorphic grid for metasedimentary rocks of the North Caribou Lake belt. Metamorphic reaction curves *after* 1 = Brown (1971); 2 = Hemley (1967); 3 = Froese and Gasparinni (1975); 4 = Hirschberg and Winkler (1968); 5 = Hoschek (1969); Aluminosilicate stability fields *after* Holdaway (1971).

Structural Geology

INTRODUCTION

The spatial relationship of folds and associated tectonite fabrics indicates that the supracrustal rocks of North Caribou Lake belt in the map area were affected by these ductile deformation events. These events, labelled D_1, D_2 and D_3, were previously unravelled in the Opapimiskan Lake area by R. Hall (geologist, Esso Minerals Limited, personal communication, 1984) and D. Rigg (geologist, Dome Explorations Limited, personal communication, 1985). Two periods of brittle–ductile shearing additionally influenced the region. Orientation of linear fabric elements in association with these deformations is given in the structural compilation map of Figure 11 (back pocket).

D_1 Deformation Event

The earliest deformation event, D_1, is rarely observed and can only be recognized with certainty in banded iron formation units that exhibit superposed folding. Folds associated with the D_1 event are tight to isoclinal, asymmetrical and deform banding in iron formation units. These folds exhibit varied, but commonly relatively flat, axial plane attitudes (example 220/30 at Musselwhite No. 1 gold showing). Rootless, intrafolial folds are defined by isoclinal quartz vein remnants enveloped by strongly penetrative S_2 foliation in host mafic and ultramafic metavolcanic rocks. This is particularly evident in the Opapimiskan Lake area and, quite possibly, may belong to F_1 fold generation.

The original pre-D_2 morphology of F_1 folds is difficult to assess since fold shapes were probably modified by rotation of fold limbs during the ensuing D_2 deformation. In Photo 31, parallelism of F_1 and F_2 fold limbs in banded iron formation can be seen.

In 5 banded iron formation exposures on the Musselwhite gold property, refolded F_1 folds occur along the limbs and crest regions of F_2 folds. As F_1 and F_2 hinges are approximately co-axial, profile views of F_2 folds most effectively reveal the superposition of their fabric elements. In grünerite-chert banded iron formation units such as at Eldorado Lake (local name), F_1 fold limbs have been tectonically destroyed, such that only rootless folds and chert-rich tectonic enclaves have survived (Photo 32).

S_1 foliations have either been obliterated or rotated into parallelism with the S_2 fabric and, hence, are rarely recognized. S_2 foliation is penetratively developed in SRV along the western shoreline of Opapimiskan Lake. Here, mesoscopic F_2 folds related to a macroscopic antiform on the Musselwhite property (Hall and Rigg 1986) deform the pre-existing S_1 foliation (Photo 33).

S_1 foliations are also preserved as planar inclusions trains in helicitic andalusite, cordierite, staurolite and garnet porphyroblasts, which lie at varied, but commonly high, angles to the enveloping S_2 foliation (Photo 34). This relationship is best observed in the Akow Lake area (Breaks, Bartlett and deKemp 1985) and Opapimiskan Lake area (Hall and Rigg 1986).

A layer parallel extension, perhaps of local significance only, was associated with the D_1 deformation. At Sage Lake, pre-D_2 quartz veins hosted in mafic metavolcanic rocks were clearly boudinaged prior to being overprinted by open D_2 mesoscopic folds.

D_2 Deformation Event

This deformation represents the major tectonic event affecting supracrustal rocks of the North Caribou Lake belt. This event is characterized by a moderately to strongly developed planar fabric (S_2 foliation), variably developed lineations, boudinage (Photo 35) and common, usually close to open, asymmetric mesoscopic folds. Recognizable macroscopic F_2 folds are particularly well developed in banded iron formation in the Opapimiskan Lake area, at Sage Lake (Photo 36) and west of Neawagank Lake.

Photo 31. Profile view of F_2 fold, which contains a refolded F_2 isoclinal fold along the crest, developed in grünerite-chert banded iron formation from "Grünerite Island" in Opapimiskan Lake. Coin diameter is 2.1 cm.

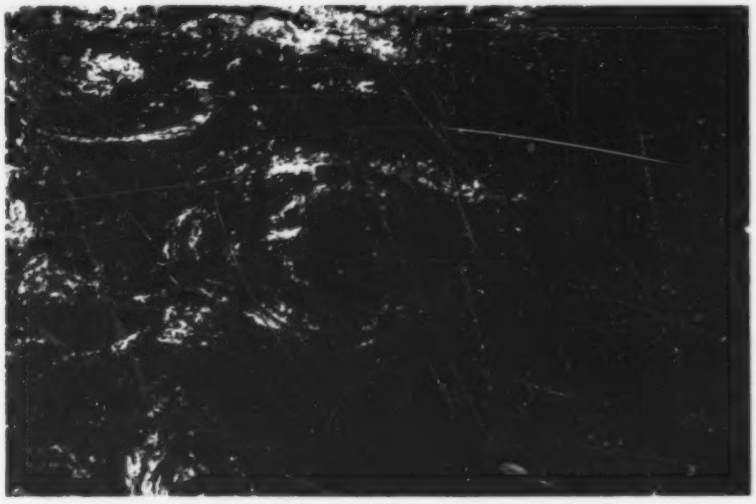


Photo 32. Rootless intrafolial F_1 fold in tectonized grünerite-chert banded iron formation near Eldorado Lake (local name) at locality M57-7. Note the preserved S_0 laminations in the hook-shaped fold remnant, which is, in turn, enveloped by an S_2 foliation. A subtle overprint by a S_3 foliation is also notable. Coin diameter is 2.3 cm.

F_2 folds are essentially cylindrical, disharmonious, and typically of Class 3 to near Class 2 type, as calculated from the t'/x diagrams of Ramsay (1967). The axial planes are near vertical and interlimb angles typically vary between 70 and 100°. The amplitude of mesoscopic F_2 folds range from 30 cm to 3 m. Typical profile sections of F_2 mesoscopic folds in banded iron formation from the Opapimiskan Lake area are shown in Figures 12 and 13, and Photos 31 and 33. Penetrative linear fabric elements accompanying F_2 folds are defined by mineral and pillow stretching, S_0–S_2 intersection in banded iron formation and boudin neck lines.

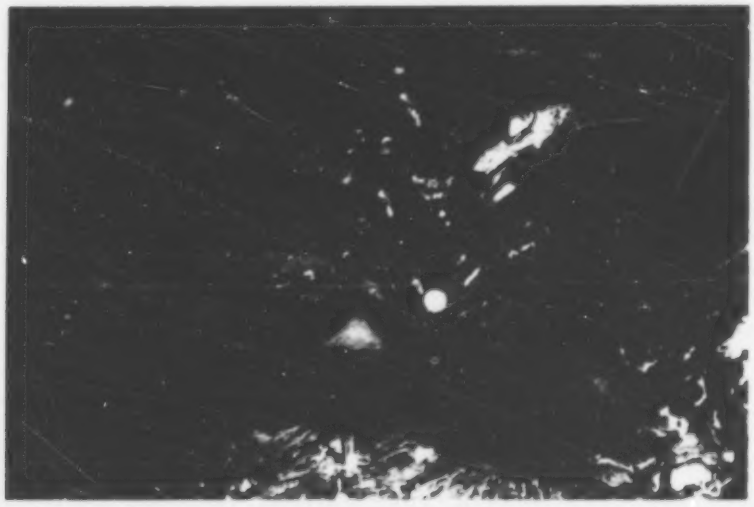


Photo 33. Strongly developed S_1 foliation in the South Rim mafic metavolcanic rocks, which is overprinted by close to open D_2 folds at locality OP151-2 on Opapimiskan Lake. Coin diameter is 2.3 cm.

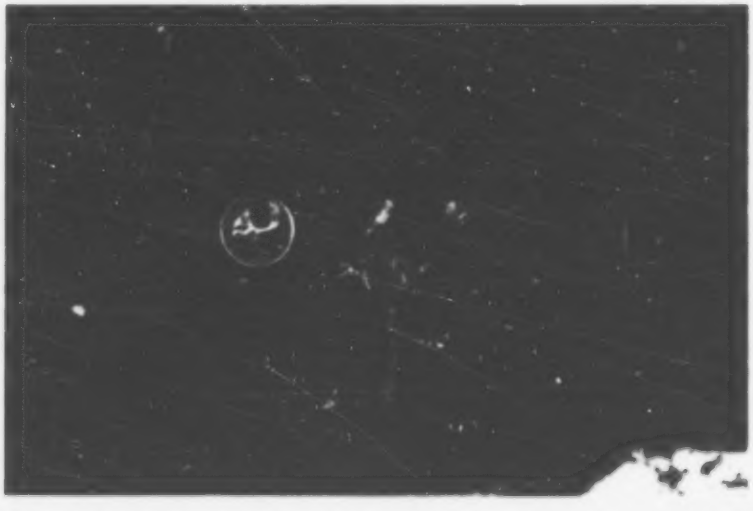


Photo 34. Sinistrally rotated garnet porphyroblast, at locality O56-11, contains an internal S_1 foliation defined by quartz-rich laminae oriented at high angle to the enveloping S_2 foliation defined by chlorite. Coin diameter is 2.3 cm.

The F_2 axial planar cleavage is a preferred locus for syn-D_2 shearing. This is particularly evident at the Musselwhite No. 1 showing, near Graf Lake, near Sage Lake and just east of Lundmark Lake (Photo 37). This period of shearing along the axial planes and limb areas of F_2 folds correlates with an increase in rust staining and grünerite content. Tectonic zones, up to 3 m wide, which occur parallel to iron formation banding, reveal a similar increase in grünerite. At the Musselwhite No. 1 gold showing, a tectonized zone in grünerite-chert banded iron formation is parallel to the axial planes of nearby mesoscopic F_2 folds (*see* "Economic Geology").

Photo 35. Asymmetrical boudinage in magnetite-chert banded iron formation at locality Q7-10 near Lundmark Lake. Note the thin grünerite layer. Coin diameter is 2.3 cm.

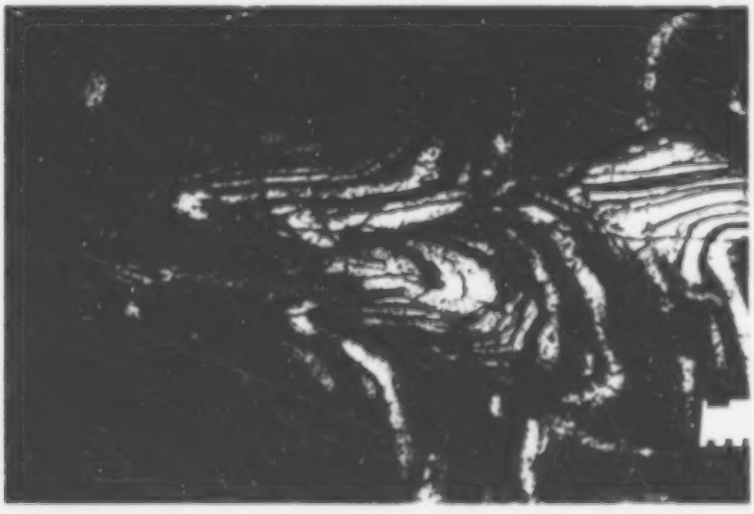


Photo 36. Mesoscopic D_2 fold in magnetite-grünerite banded iron formation situated 250 m north of Sage Lake. Note the 2 ages of brittle faulting, and similarity in fold morphology to those in the Opapimiskan Lake area (*see* Figure 10).

D_3 Deformation Event

The third deformation event, D_3, marks a period of inhomogeneous strain. It is observed only as locally pervasive, mesoscopic, open to gentle, asymmetric F_3 warps and chevron crenulations of D_2 foliations and axial planar cleavage (Photo 38). These cylindrical folds are commonly Z-shaped, with upright axial planes and amplitudes of less than 1 cm up to 5 cm. These folds occur sporadically throughout the map area and characteristically possess axial planes oriented subnormal to the greenstone belt boundaries.

Locally, the D_3 folding was intense enough to have developed a crenulation cleavage, which clearly overprints D_2 cleavages in grünerite-rich mesobands in iron formation (e.g., near "Grünerite Island" on Opapimiskan Lake) or in ultramafic metavolcanic rocks (western end of Zeemel Lake). Hall and Rigg (1986, p.129) recognized similar folds in underground workings of the West Anticline Zone of the Musselwhite property. Gold mineralization was noted to be locally associated with the D_3 deformation event (R. Hall, geologist, Esso Minerals Canada, personal communication, 1987).

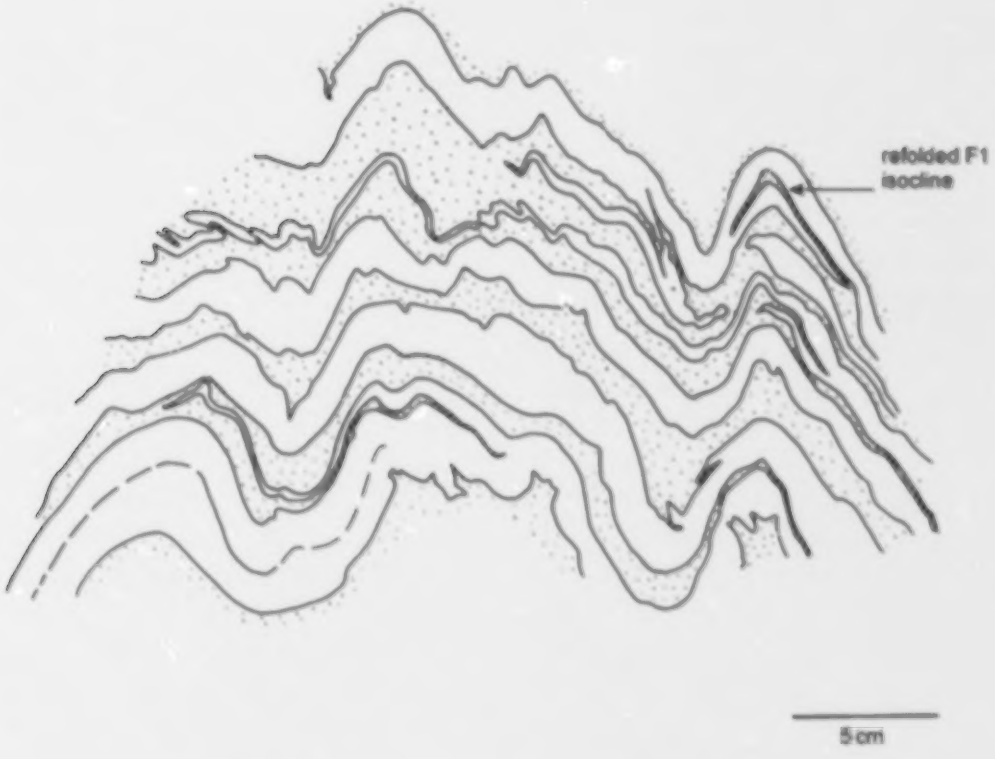


Figure 12. Profile view of F_2 folds in grünerite-chert banded iron formation at "Grünerite Island" of Opapimiskan Lake. Refolded F_1 isoclinal folds and F_3 undulations along the chert-grünerite-rich contacts are also discernible.

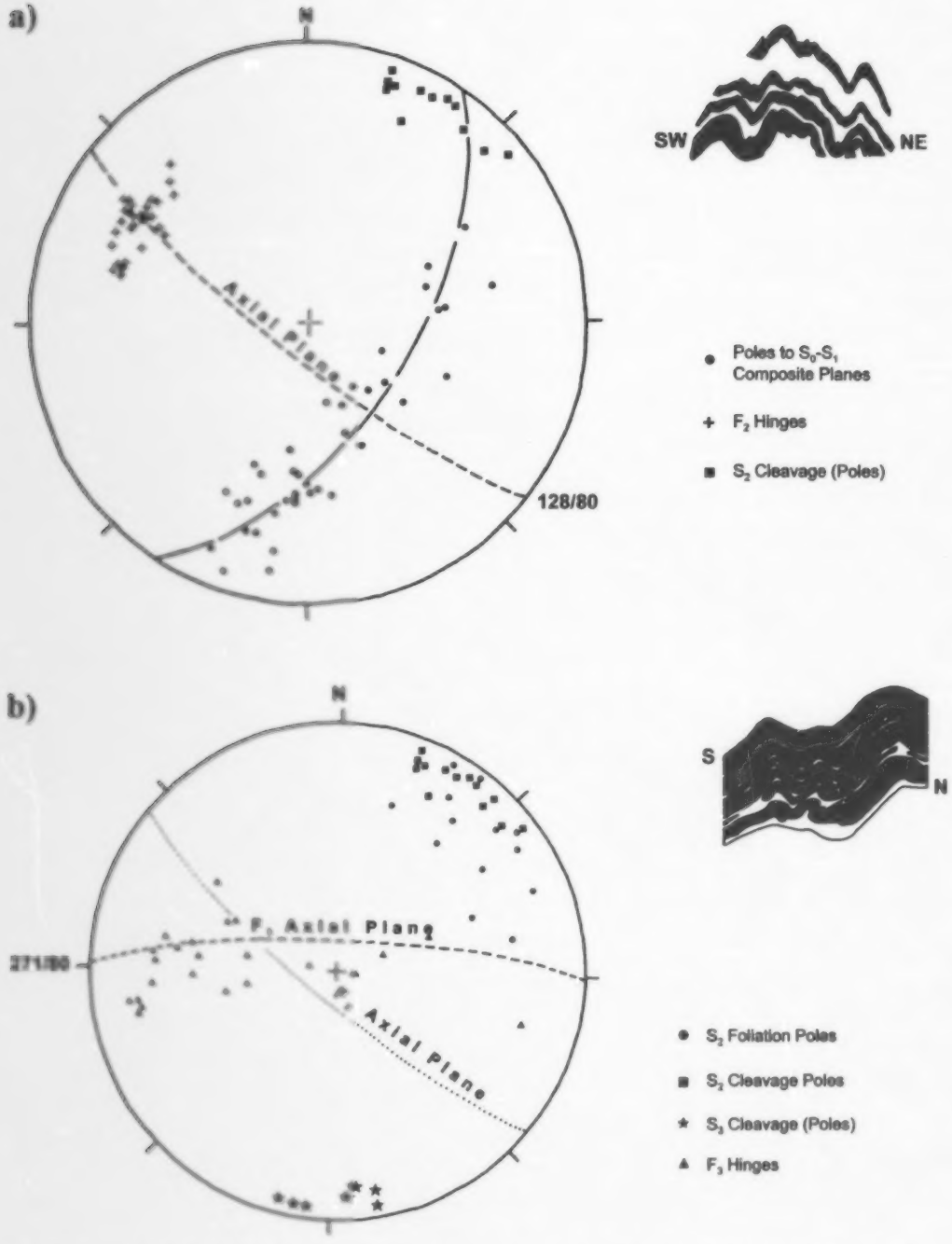


Figure 13. Lower hemisphere Schmidt equal-area stereonet projection of structural elements related to (a) F_2 folds and (b) F_3 folds from the Opapimiskan Lake area.

Macroscopic F_3 folds may exist in the map area. This is suggested by sudden reversals in the trend of D_2 lineations in the Sage–Neawagank lakes area, as observed near the Pipestone River and north of Opapimiskan Lake, which would be expected from broad warping of the greenstone belt about fold axes perpendicular to its contact.

Photo 37. Mesoscopic F_2 fold with radial axial planar cleavage in magnetite-grünerite-chert banded iron formation, abruptly truncated along the right limb by a syn-D_2 shear zone, at locality O56-4 near Lundmark Lake. Coin diameter is 2.3 cm.

Photo 38. F_3 flexural slip folds in grünerite-chert banded iron formation at locality O56-4 near Lundmark Lake. Coin diameter is 2.3 cm.

Interference Structures

Superposition of F_1–F_2 and F_1–F_2–F_3 fold fabric elements has led to development of interference structures in some rock types of the Opapimiskan Lake area. Interference of F_1 and F_2 folds may yield basin-and-dome patterns, which are classed as Type 1 fold interference structures by Ramsay (1967). A spectacular example, exposed in grünerite-chert banded iron formation, occurs on "Grünerite Island" (local name) of Opapimiskan Lake. This structure (Photo 39) is produced by intersection of F_1 and F_2 hinges and axial planes at relatively high angles (Ramsay 1967). The sinuous warping of this canoe-like structure relates to subtle overprinting by F_3 folds.

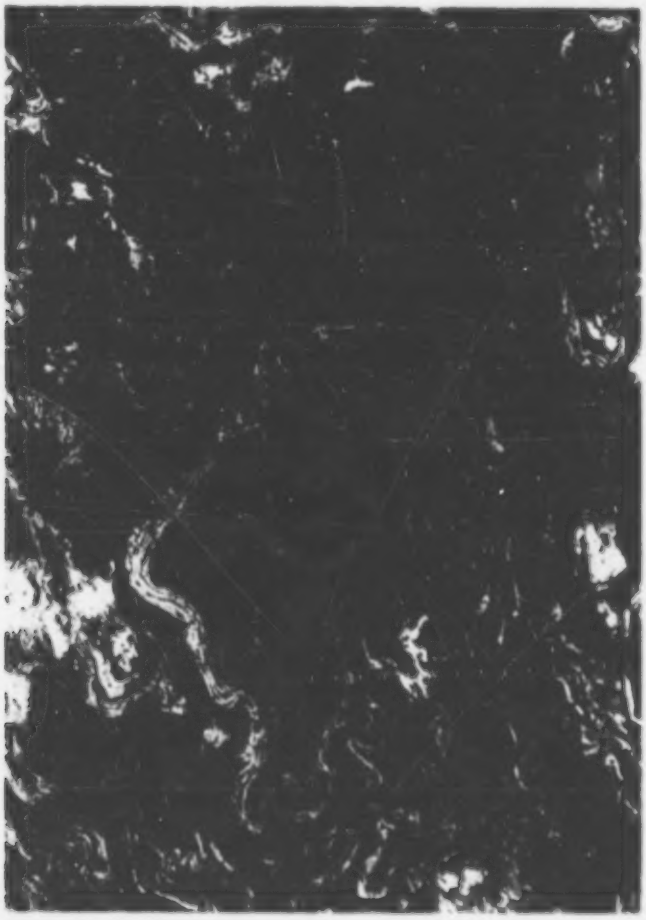


Photo 39. Spectacular Type 1 interference folds in grünerite-chert banded iron formation on "Grünerite Island", Opapaimiskan Lake. Coin diameter is 2.3 cm.

More commonly, F_1–F_2 interference produces the Type 3 class of Ramsay (1967), marked by coaxiality of respective fold hinges. At the Musselwhite No. 1 gold showing, F_1–F_2–F_3 folds exhibit interfering relations. The dominant tight to isoclinal F_1 folds (axial plane 220/30NW) are refolded by open F_2 folds. Axial planar cleavage (310/85NE) and associated quartz lens emplacement are associated with the second generation of folds. Local modification is effected by F_3 folds (axial plane 065/90), which were responsible for the Z-shaped, open buckling evident in the limb zones of F_1 folds.

Shear Zones

The North Caribou Lake belt is transected by several important ductile–brittle shear zones, which were undocumented prior to this study (Figure 11). These syn- to late-D_2 deformation systems, as listed in Table 5, affect all supracrustal assemblages and are generally guided by zones of competency contrast. Timing of these shear zones can be constrained as dominantly syn- to late-D_2, since their deformation fabric is overprinted by the D_3 fold event. Detailed descriptions of the various shear zones can be found in Breaks and Bartlett (1991), Breaks et al. (1991) and Piroshco (1986). Mesoscopic shear zones are especially abundant in the AAV, in the Agutua Arm area, and in the SRV, along the western shoreline of Opapimiskan Lake, and were probably generated syn- to late-D_2.

Later shearing events are mainly of a brittle nature and have been assigned to the D_4 deformation event-generated cohesive fault breccia and associated pseudotachylite, as noted in arenaceous metasedimentary rocks near the eastern end of Zeemel Lake. Local regeneration of faulting may have also manifested in D_2 ductile shear zones as in the Akow Lake fault. This is indicated by pseudotachylite and carbonate-cemented angular fault breccia showing randomly oriented D_2 mylonite fragments.

Geophysics

INTRODUCTION

An airborne magnetic–electromagnetic survey was flown in the North Caribou Lake area, during the period March to April 1985, by Aerodat Limited under contract to the Ontario Geological Survey, Toronto. A total of 15 195 km of survey lines were flown at an average flight line spacing of 200 m and tie line spacing of 3 km. The flight line directions maintained perpendicularity to the regional geologic strike. Mean terrain clearance was 45 m for the magnetometer sensor and 30 m for the electromagnetic sensor. Results of the survey were released as 38 maps (Ontario Geological Survey 1985).

Table 5. Some features of important brittle–ductile fault zones of the North Caribou Lake belt.

Fault Zone	Length (km)	Width (m)	Relative Movement	Lithologic Control(s)
North Caribou Lake fault	35	50–300	Left-lateral	Uncertain (possibly primary volcanic to contact between SRV and AAV in part; elsewhere between ELS and SRV)
North Rim fault	35	200	Left-lateral	Contact between NRV and ELS
Dinnick Lake fault	>30	300	Left-lateral	Contact between NRV and Schade Lake gneisses
Akow Lake fault	>10	200	Left-lateral	Contact between SRV and ELS
Markop Lake fault	13	150–1500	Right-lateral	Contact between FLV and ELS

The helicopter-borne electromagnetic system measured in-phase and quadrature components at 3 frequencies, employing 2 vertical coaxial coil pairs operating at 932 and 4600 Hz and are copolar coil pair operating at 4168 Hz. The electromagnetic data were sampled at 0.1 second intervals employing a 0.1 second time constant. In addition to bedrock conductors, the helicopter electromagnetic system responds to conductive overburden and near-surface horizontal conducting layers. Conductance and depth estimates were determined, assuming a vertical half-plane model in free space, at 935 Hz (signal to noise permitting) where conductive overburden effects are minimal.

A Geometrics G-803 Proton procession-type magnetometer was included with the electromagnetic system. Aeromagnetic total field data were digitally recorded at a sampling interval of 0.5 seconds. These magnetic data were corrected for diurnal variations, and were interpolated onto a regular 0.25 cm grid, at the map scale of 1:20 000. No correction was made for the regional variation of the Earth's magnetic field.

CORRELATION OF GEOLOGY WITH THE MAGNETIC AND ELECTROMAGNETIC DATA

The correlation of rock types with geophysical patterns considerably assisted the authors in identifying drift-covered rock units, extrapolating contacts and recognizing major geological structures. For most of the study area, aeromagnetic data can easily locate contacts between major supracrustal units, and between the greenstone belt and adjacent granitic plutons. In general, the more ferromagnetic the rock type (iron formation, mafic–ultramafic rocks and magnetite-bearing granites), the greater the magnetic response. The exception to this rule is where ferromagnetic rocks were subjected to intense post-emplacement alteration causing a reduced magnetite content.

Owing to the abundance of iron formation, the magnetic relief is relatively high in the study area. The absolute total-magnetic field measurements range from less than 59 000 gammas to more than 68 000 gammas (Ontario Geological Survey 1985).

The magnetic contour maps show anomalies rising more than 9300 gammas above the background at Opapimiskan Lake, 6000 gammas in the Libert, Akow and Lundmark lakes area, 4300 gammas in the Sage–Neawagank lakes area, and up to 3800 gammas at McGruer Lake and 3200 gammas in the Graff Lake area. Anomalies of such amplitudes undoubtedly reflect either one thick iron formation unit or numerous thin units.

The rocks in the Opapimiskan Lake area are folded into a series of broad antiforms and tight synforms. These structures can be recognized on the aeromagnetic maps (Ontario Geological Survey 1985, Maps 80740 and 80743) using the iron formation as marker units. The geophysical data, in combination with diamond drill data, have revealed 3 iron formation units in the area. These are termed the "northern, middle and southern ironstones" (Hall and Rigg 1986).

The aeromagnetic data (Ontario Geological Survey 1985, Maps 80751 and 80752) in the Sage and Neawagank lakes area also indicate complex folding of supracrustal sequences. The high magnetic relief (up to 4300 gammas) in the authors' opinion, reflects several structurally repeated iron formation units. Relatively low, linear magnetic anomalies with between 500 and 2000 gammas of relief, generally correspond to narrow, lean, grüneritized iron formation units. An example occurs along the contacts between metasedimentary and metavolcanic rocks to the north of Eyapamikama Lake, where predominantly grüneritized iron formation occurs discontinuously over a strike length of approximately 18 km between Stanley and Arseno (local name) lakes.

Mafic metavolcanic rocks correspond chiefly to areas characterized by linear positive anomalies 60 450 to 6100 gammas). In some places, altered mafic metavolcanic rocks, coincide with areas of very low magnetic intensity. The magnetic relief of these generally does not exceed a few hundred gammas, except where iron formation units are intercalated with the mafic flows. The mafic metavolcanic rocks generally strike parallel to the belt margins and are easily distinguished from the adjacent granitic plutons by their linear, modest magnetic anomalies.

The ultramafic metavolcanic rocks cannot be delineated with absolute certainty using aeromagnetic data. In most places, these rocks occur interlayered with iron formation, so that their relatively weak magnetic characteristic is masked by the much stronger magnetic response of the iron formation. Examples of this are found in the extensive meta-ultramafic-rich sequences, which occur in the Graff, Opapimiskan, Libert and Forester lakes areas. The areas with limited or no outcrops, showing linear magnetic anomalies with intensity rising up to 62 000 gammas or more, can possibly be interpreted on the basis of known occurrences in the study area. The intercalated iron formation and ultramafic metavolcanic rocks as the possible source of these anomalies.

Metasedimentary sequences, which are mainly confined within the core of the belt, are characterized by broadly spaced positive and negative anomalies of lower magnetic intensity. Through most of the belt, the metasedimentary rocks are flanked by linear anomalies of moderate intensity, which correspond to the mafic–ultramafic metavolcanic rocks.

Small mafic to ultramafic bodies intrude both concordantly and discordantly the metavolcanic and metasedimentary sequences throughout the belt. Aeromagnetic data cannot be used to delineate these small bodies. However, larger bodies, which are mapped in the Karl and Neawagank lakes area, are readily recognized on aeromagnetic maps (Ontario Geological Survey 1985, Maps 80745 to 80752). For example, around the western half of Karl Lake, the mafic to ultramafic bodies, comprising pyroxenite, gabbro and amphibolite, are characterized by moderate magnetic relief with positive anomalies up to 1450 gammas above background. The relatively high magnetic content (up to 7%) in these rocks is undoubtedly responsible for generating magnetic relief of such amplitude.

To the north and northeast of Wesley Lake, in the Neawagank Lake area, mafic intrusive rocks, consisting of homogeneous gabbro, leucogabbro, anorthositic gabbro and local anorthosite patches, correspond to east-striking, elliptical positive anomalies with low intensity (maximum 60 200 gammas). This reflects the low magnetic content in these rocks, which is generally less than 1%.

Granitic rocks, adjacent to the greenstone belt, generally correspond to large areas of low to medium magnetic intensity, characterized by broad, diffuse anomalies without preferred orientation. In some areas, these rocks, especially gneisses, can contain appreciable magnetite and coincide with linear, oval or circular anomalies with moderate to relatively high intensity. For example, in the Karl Lake area, several oval to circular anomalies with maximum magnetic intensity ranging from 60 650 to 61 750 gammas (Ontario Geological Survey 1985, Maps 80742 and 80745), conform to highly ferromagnetic granite, granitic pegmatite and gneissic tonalite, which contain up to 5% magnetite.

The northeast- and northwest-striking diabase dikes generally produce large linear aeromagnetic anomalies. The anomalies over the northeast-striking dikes, which are situated in the Zeemel–Opapimiskan lakes area, and the Graff Lake area, have maximum magnetic relief up to 150 and 190 gammas, respectively (Ontario Geological Survey 1985, Maps 80741, 80743, 80744 and 80749). A diabase dike of similar magnetic attitude is also exposed on an island at the eastern end of Eyapamikama Lake (Ontario Geological Survey 1985, Map 80729). A northwest-trending, linear anomaly, which lies over the western part of Eyapamikama Lake, has a magnetic relief of up to 620 gammas (Ontario

Geological Survey 1985, Maps 80718, 80726 and 80734). This anomaly is interpreted, though it has not been verified on the ground, as a highly ferromagnetic diabase dike.

Faults and deformation zones can be interpreted using geophysical data, in conjunction with available geological information. In certain areas, faults are reflected by abrupt displacements or by changes in magnetic patterns. One example of the latter is the contrast in magnetic trend along the eastern shore of Neawagank Lake. There, a fault is assumed to lie between the area characterized by the northeast-trending patterns west of Neawagank I ake, and the east-trending patterns found east of the lake. Similar changes in magnetic patterns are noted just west of Eyapamikama Lake, where a fault is assumed to lie between the east- and northwest-trending magnetic lineations. This interpretation is reinforced by the presence of tectonic fragments in the conglomerates at Keeyask Lake, intensely sheared and carbonatized mafic to ultramafic metavolcanic rocks east of the fault, and tectonic iron formation breccia southwest of Eyapamikama Lake.

Between Markop Lake and the Pipestone River, there is a 13 km long, 150 to 1500 m wide, northeast- to east-trending deformation zone (Markop Lake deformation zone). The western half of this zone is characterized by numerous northeast- to east-striking shear and mylonite zones. The eastern half is mainly interpreted using the geophysical data. There, the individual deformation structures which make up the zone are well defined by "trains" of moderate to strong electromagnetic conductors. Several drill holes along these structures are reported to have intersected sulphide-bearing zones hosted by moderately deformed schistose rocks (assessment files, Resident Geologist's office–Thunder Bay North, Thunder Bay, Ontario) (for details, *see* "Structural Geology").

The airborne electromagnetic survey provides a good reconnaissance tool for mineral explorationists in the North Caribou Lake area. Most sulphide and graphite zones appear to occur along contacts between lithologic units within the belt, and between the belt and adjacent granitic rocks. These conductive contacts probably merit verification by follow-up surveys on the ground.

Weak to strong (between 4 and >32 ohms) electromagnetic conductors occur along certain shear and/or fault zones. These zones should be surveyed for several hundred metres on either side of their axes by induced polarization and/or resistivity methods for disseminated sulphide zones, which may be indicative of hydrothermal alteration and possible precious metal mineralization.

Several other interpretations about the North Caribou Lake belt can be made on the basis of airborne magnetic data.

1. In the southeastern and eastern portion of the belt, a previously unrecognized metavolcanic sequence is traceable for 32 km along the northern part of the belt. It extends continuously from just west of the Pipestone River to the eastern extremity of the map area. The extension of this sequence, in part, is guided by a few available outcrops.
2. An unexposed, narrow metavolcanic sliver, which probably contains discontinuous iron formation units, occurs at Wapuskeya Lake in the central portion of the belt. This unit is separated from the main belt by a granitic body and the "Dinnick Lake fault zone".
3. An unexposed, approximately 2 km long and 600 m thick metavolcanic sequence occurs 3 km north of Norbury Lake. The magnetic relief of the anomaly, which is up to 2100 gammas, reflects the presence of an iron formation unit, enclosed within the metavolcanic sequence.
4. A northeast-striking fault, interpreted to occur west of Markop Lake, has been redefined by geological mapping and the geophysical data (Ontario Geological Survey 1985, Maps 80744, 80745, 80746, 80749 and 80750) as the "Markop Lake deformation zone". This zone is interpreted as a curvilinear structure, which is subparallel to lithological units on its northeast portion, but truncates the units to the southwest.

Economic Geology

Properties containing important mineralization have been discussed by Breaks and Bartlett (1991), Breaks et al. (1991) and Piroscho, Breaks and Osmani (1989). The following will, therefore, provide some guidance as to which mineralization environments offer the best exploration potential.

RECOMMENDATIONS FOR FUTURE MINERAL EXPLORATION

The mineral potential for the North Caribou Lake belt is considered high in light of recent significant gold discoveries at Opapimiskan Lake and a recognition, by this survey, of many distinct habitats for gold mineralization, in addition to revealing more localized, anomalous levels of platinum group elements.

Gold

Gold mineralization is now known to occur in 7 supracrustal assemblages of the North Caribou Lake belt, as summarized in Table 6, and involves the following generalized environments:

1. grünerite-magnetite-chert
2. tourmaline-carbonate quartz veins (pre-D_2), and
3. syn-D_2 shear zones

BANDED IRON FORMATION-HOSTED GOLD MINERALIZATION

The best target for gold mineralization is considered to be highly deformed silicate-oxide facies banded iron formation. These units, which abound within the map area, are host to the most significant gold mineralization in the North Caribou Lake belt at Opapimiskan Lake, where approximately five million tons, grading 6.80 g/t gold, has thus far been delineated (R. Hall, geologist, Esso Minerals Canada, personal communication, 1988).

Specifically, gold mineralization associated with banded iron formation at the Musselwhite No. 1 showing occurs in 4 situations:

1. quartz-pyrrhotite veins concordant to D_2 axial planes
2. syn- to late-D_2 shear zones mineralized with arsenopyrite, pyrite and pyrrhotite
3. albite-rich granitoid dikes subparallel to D_2 axial planes, and,
4. metasomatic selvages distributed along albite-rich granitoid dikes.

Gold mineralization associated with arsenopyrite-pyrite-bearing albite-rich granitic pegmatite dikes and attendant metasomatic selvages exhibit a clear association with anomalous levels of rare metals, in particular lithium, rubidium, tantalum and tin.

Tantalum contents of the dikes range from 80 to 140 ppm, considerably elevated above the estimated crustal abundance of 2 ppm (Mason 1966). The Nb/Ta ratio in these dikes of 0.1 to 0.18 departs significantly from the crustal average of 10 (Mason 1966, p.45-46), also indicating significant geochemical fractionation. To the authors' knowledge, the metallogenic association of gold with rare metals has not been previously recognized in the Superior Province and the potential should be more closely examined in other areas.

Table 6. Types of gold mineralization associated with the important supracrustal assemblages of the North Caribou Lake belt.

Supracrustal Assemblage	Mineralization Type	Gold	Silver	Examples
I. Agutua Arm metavolcanic rocks	Ankerite-sulphide quartz veins in carbonatized D_2 shear zones	3.4–1115 ppm 530–4200 ppb	32.2–3011 ppm 72–100 ppm	Teal Cu-Ag-Au occurrence North Caribou River occurrence
	Arsenopyrite-chalcopyrite-pyrite quartz veins in carbonatized mafic metavolcanic rocks	5 ppb to 72.6 ppm	<2–36 ppm	Pyrotex Cu-Au-Ag occurrence
II. Keeyask Lake metavolcanic rocks	Pyrite-arsenopyrite carbonatized meta-ultramafic rocks	380–470 ppb		Centre Lake Au occurrence
III. Eyapamikama metasedimentary rocks	Arsenopyrite-bearing interbanded metapelite and dolomitic marble	1.4 ppm		Castor Lake
IV. North Rim metavolcanic rocks	Grünerite + magnetite banded iron formation, with local arsenopyrite, pyrrhotite	1.4–7.2 ppm		Castor Lake
	Arsenopyrite-tourmaline; Quartz vein in banded iron formation	10.7 ppm (grab sample) 5.1 ppm over 1.7m		McGruer Lake Au occurrence
	Grünerite + magnetite banded iron formation with arsenopyrite, sphalerite, galena	4.9% Pb, 3.6% Zn, 274 ppm Au, 1.4 ppm Au		Arseno Lake Pb-Zn-Ag-Au occurrence
V. Opapimiskan Lake volcanic rocks	Grünerite-magnetite banded iron formation associated with mafic	3.2 million tons averaging 5.8 ppm		Musselwhite deposit, Opapimiskan Lake (Musselwhite No. 1 and No. 2 Everway showing)
		3 ppm over 3.3 m to 1444 ppm over 15 cm		Van Horne Resources Au occurrence, North Opapimiskan Lake
		4.4 ppm over 3.6 m		Paseminon River occurrence
VI. South Rim metavolcanic rocks	Arsenopyrite-pyrite-bearing shear zone in mafic metavolcanic rocks	605–4630 ppb		Seeseep Channel occurrence
	Tourmaline-sulphide-carbonate quartz vein in mafic metavolcanic rocks	8.2 ppm over 6.1 m		Kenpat No. 1 Vein, Opapimiskan Lake
VII. Forester Lake metavolcanic rocks	Arsenopyrite-pyrite shear zone in metagabbro	2.5–14.4 ppm		Wesley Lake occurrence

Gold-bearing, syn-D_2, albite-rich dikes, which occur at the Musselwhite No. 1 gold showing, as reported by Breaks, Bartlett and deKemp (1985, p.274), plausibly originated from a small mass of tourmaline-garnet-muscovite granite and granitic pegmatite situated 7 km to the southeast. This small stock, approximately 0.5 km^2 in area, is enveloped by muscovite-biotite metapelites and metawackes, and possibly originated via anatexis of such rocks at a deeper crustal level. D_2 boudinaged dikes of identical rock, with biotite-tourmaline metasomatic halos occur in garnet-biotite pelite on the nearby Paseminon River.

Widespread distribution, albeit in scant quantities, of segregations enriched in tourmaline and biotite is notable in the Opapimiskan Lake metavolcanic assemblage, especially in massive komatiitic flows and pillow selvages in mafic metavolcanic rocks located in the Graff Lake area. and on the Musselwhite gold property.

This boron-potassium metasomatism possibly relates to volatile-charged, albite-rich granitic pegmatite dikes emanating from peraluminous granitoid masses similar to that described above. Veins of similar material were emplaced discordant to the S_2 foliation in metasedimentary rocks near Libert Lake, which were subsequently overprinted by close to tight D_2 folds.

Grünerite-magnetite banded iron formation in the Sage Lake area represents a very desirable gold target. This unit has a similar lithologic setting and structural history to banded iron formation on the Musselwhite property. Gold mineralization has been intersected in diamond drill holes completed by the International Nickel Company of Canada (assessment files, Resident Geologist's office–Thunder Bay North, Thunder Bay, Ontario). Banded iron formation units, immediately south of Sage Lake, possibly represent gold targets of equal rank, however, the paucity of exposure inhibits such comparisons. These units are inferred to have comparable fold styles based upon aeromagnetic information (Ontario Geological Survey 1985).

More exploration is recommended for the banded iron formation units outside the Opapimiskan Lake area, in particular on portions covered by Quaternary overburden. The exposed zones of relatively intense shearing, boudinage and grüneritization in the Akow–Eyapamikama lakes banded iron formation merit closer investigation as sulphide mineralization and consequent gossan development in these units appears to correlate with increased deformation.

In view of the association of grünerite-magnetite chert banded iron formation, ultramafic metavolcanic rocks and gold mineralization at the Musselwhite and Van Horne properties in the Opapimiskan Lake area, it may be prudent to consider the possibility of a similar mineralization within the Eyapamikama–Akow lakes banded iron formation unit. Much of this unit is covered by ground moraine till deposits. Given the extensive total strike length of banded iron formation within the map area and typical limited exposure, proper evaluation of stratabound gold mineralization will require diligent exploration. It should be stressed that aeromagnetic patterns may become increasingly muted as conversion of magnetite into grünerite progresses toward completion. This is exemplified in the Castor–Pollux lakes area, where subtle elongate aeromagnetic anomalies (gammas magnetic relief) coincide with grünerite-chert banded iron formation containing a paucity of magnetite.

SHEAR ZONE-HOSTED GOLD MINERALIZATION

Major ductile to brittle shear systems are widely developed throughout the North Caribou Lake belt and, in many cases, contain gold and/or silver mineralization. These zones, which are commonly marked by "trains" of electromagnetic conductors of varied intensity, should be thoroughly investigated for gold mineralization. North of Opapimiskan Lake are noteworthy anomalous gold values up to 550 ppb

(assessment files, Resident Geologist's office–Thunder Bay North, Thunder Bay, Ontario) associated with arsenopyrite within a prominent shear zone controlled by the contact of North Rim metavolcanic assemblage with the Eyapamikama Lake metasedimentary assemblage.

In the Neawagank Lake area, gold occurs in an east-striking shear zone northeast of Wesley Lake. Gold is associated with massive to disseminated (1 to 2%) arsenopyrite-pyrite-pyrrhotite veinlets, which are hosted by sheared, quartz gabbro to diorite. Assay values of 0.074 to 0.42 ounces of gold per ton were recorded in work undertaken in the 1940s (assessment files, Resident Geologist's office–Thunder Bay North, Thunder Bay, Ontario). Quartz veins and veinlets from the same shear zone were found by this survey to contain only small amounts of disseminated sulphide mineralization and traces of gold. Bands of iron formation delineated from aeromagnetic maps (Ontario Geological Survey 1985) appear to be complexly folded and sheared in several places. These bands should be considered prime targets for gold mineralization.

Silver-Zinc-Lead-Copper Mineralization

Shear zone-hosted mineralization of a possible epithermal character was discovered by F.W. Breaks and described as the North Caribou River occurrence in Breaks and Bartlett (1991, p.66-67). The occurrence is similar in mineralogy and geological setting to the nearby Teal copper-silver-gold occurrence, most recently described by Piroshco, Breaks and Osmani (1989). The occurrence exhibits deformed layers of sphalerite-pyrite-chalcopyrite-quartz-brown carbonate, which are crosscut by calcite-rich veins. The late veins contain galena, tetrahedrite (32.2% Ag), pyrite and sparse flakes of native silver. A silver–antimony phase (Ag_6Sb), which contains 15.6 to 15.8% Sb, is partly intergrown with pyrite in late fractures (R. Thorpe, Geologist, Geological Survey of Canada, personal communication, 1990). A Pb/Pb model age of 2827 was determined on the galena from this occurrence by R. Thorpe and G. Cumming (R. Thorpe, Geologist, Geological Survey of Canada, personal communication, 1990).

Zinc-Copper-Lead Massive Sulphide Mineralization

In 1987, Northern Dynasty Explorations Limited discovered base metal mineralization near Arseno Lake (local name). A deposit of 1 million tonnes with an average grade of 8.7% combined Zn and Pb with 1.5 ounces of silver was outlined in diamond drill work (Northern Dynasty Explorations Limited, 1988 Annual Report). The mineralization occurs as sphalerite, galena, pyrrhotite, pyrite and chalcopyrite hosted in siliceous iron formation of the North Rim metavolcanic assemblage. A 700 m thick ductile deformation zone, which is a westward extension of the same zone found in the Castor–Pollux lakes area, overprints the mineralizations and renders tenuous inferences regarding the origin of the mineralization. Janes, Seim and Storey (1990) concluded that the deposit resulted from "syn-volcanic hydrothermal activity". The large time-gap between the age of the North Rim metavolcanic rocks (2932±3 Ma, Davis 1990) and the model age of the galena of 2850 to 2852 Ma (R. Thorpe, Geologist, Geological Survey of Canada, personal communication, 1990) implies an epigenetic origin for the mineralization.

Platinum Group Elements

Anomalous trace levels of platinum and palladium were encountered in previously undocumented sulphide-mineralized amphibolitic rocks occurring in 2 localities within the Karl Lake intrusive complex (Breaks et al. 1986). This mafic–ultramafic intrusive complex, as well as others mapped in the area, merits a closer examination with regard to these metals.

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Metric Conversion Table

Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
		LENGTH			
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
		AREA			
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
		VOLUME			
1 cm^3	0.061 023	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.307 951	cubic yards	1 cubic yard	0.764 554 86	m^3
		CAPACITY			
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
		MASS			
1 g	0.035 273 962	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 747	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 622 6	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311 3	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 90**	t
		CONCENTRATION			
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	31.103 477	grams per ton (short)
1 gram per ton (short)	0.032 151	ounces (troy) per ton (short)
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.

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